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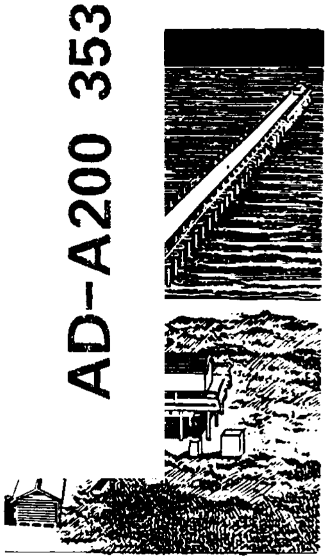

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TECHNICAL REPORT CERC-88-13

ST. PAUL HARBOR, ST. PAUL ISLAND, ALASKA DESIGN FOR WAVE AND SHOALING PROTECTION

Hydraulic Model Investigation

by

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

A 1:75-scale three-dimensional hydraulic model was used to investigate the design of a proposed breakwater extension at St. Paul Harbor, St. Paul Island, Alaska, with respect to wave and shoaling conditions. The model reproduced approximately 13,500 ft of the island shoreline and included the existing harbor (located in Village Cove) and sufficient offshore area in the Bering Sea to permit generation of the required test waves. Improvement plans consisted of extensions to the existing breakwater and the installation of breakwater spurs and a new secondary breakwater structure. A 60-ft-long unidirectional, spectral wave generator, an automated data acquisition and control system, and a crushed coal tracer material were utilized in model operation. It was concluded from test results that:

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19. ABSTRACT (Continued).

a. Existing conditions are characterized by very rough and turbulent wave conditions (wave heights in excess of 10 ft) along the vertical-walled dock during periods of storm wave attack.

b. The originally proposed breakwater extension with the 1,000-ft-long vertical walled dock (Plan 1) resulted in excessive wave heights (6.8 ft) along the proposed dock. Modifications to this plan, which consisted of the installation of spurs and/or a secondary breakwater, resulted in wave heights in excess of the established wave height criterion of 2.5 ft at the dock.

c. Of the improvement plans tested with the 750-ft-long vertical-walled dock (Plans 9-43), several met the established 2.5-ft wave height criterion at the dock. These improvement plans were not optimal, however, regarding navigation through the proposed entrance configurations.

d. Of the improvement plans tested considering a pile-supported dock system (Plans 44-59), several met the 2.5-ft wave height criterion in the new mooring area situated in the lee of the secondary breakwater.

e. Of all the improvement plans tested (Plans 1-59), Plan 47 was determined optimum considering wave protection, navigation, harbor circulation, and costs. The 2.5-ft wave height criterion will be exceeded by 0.1 ft only for the most severe incident storm wave conditions from west-northwest.

f. The Plan 47 breakwater configuration will have no adverse impact on the movement of sediment in the area, nor will shoaling occur in the harbor entrance or mooring areas.

g. The 200-ft opening between the secondary breakwater of Plan 47 and the shoreline will provide for increased wave-induced harbor circulation.

PREFACE

A request for a model investigation of wave and shoaling conditions at St. Paul Harbor, St. Paul Island, Alaska, was initiated by the US Army Engineer District, Alaska (NPA), in a letter to the US Army Engineer Division, North Pacific (NPD). Authorization for the US Army Engineer Waterways Experiment Station (WES) to perform the study was subsequently granted by Headquarters, US Army Corps of Engineers (HQUSACE). Funds were authorized by NPA on 19 May 87, 8 Jul 87, 12 Aug 87, 27 Aug 87, 10 Sep 87, 2 Oct 87, 30 Nov 87, 21 Dec 87, and 31 Dec 87.

Model testing was conducted at WES during the period Aug-Dec 1987 by personnel of the Wave Processes Branch (WPB), of the Wave Dynamics Division (WDD), and Coastal Engineering Research Center (CERC), under the direction of Dr. J. R. Houston, Chief, CERC; Messrs. C. C. Calhoun, Jr., Assistant Chief, CERC; C. E. Chatham, Jr., Chief, WDD; and D. G. Outlaw, Chief, WPB. The tests were conducted by Messrs. M. G. Mize, H. F. Acuff, and L. R. Tolliver, Civil Engineer Technicians, WPB, under the supervision of Mr. R. R. Bottin, Jr., Project Manager, WPB. This report was prepared by Messrs. Bottin and Mize, and edited by Mrs. N. Johnson, Information Technology Laboratory, under the Inter-Governmental Personnel Act.

Prior to the model investigation, Mr. Bottin met with representatives of NPA and visited St. Paul Island to inspect the prototype site. During the course of the investigation, liaison was maintained by means of conferences, telephone communications, and monthly progress reports.

Messrs. S. Powell and G. Drummond of HQUSACE; J. Oliver and A. Ramirez of NPD; D. Hendrickson, C. Stormer, K. Eisses, J. DeLeo, C. Borash, S. Christian, and J. Burns, of NPA; J. Weckmann, G. Watts, and A. Shak, of Tetra Tech, Inc.; A. Mandregan, Mayor, St. Paul; and M. Zacharot, J. Merelief, V. McCorkle, and R. Philemonoff, of St. Paul; visited WES to observe model operation and participate in conferences during the course of the study.

COL Dwayne G. Lee, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	metres
miles (US statute)	1.609347	kilometres
pounds (force)	4.448222	newtons
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
square miles	2.589988	square kilometres
tons (2,000 pounds, force)	8,896.444	kilonewtons

ST. PAUL HARBOR, ST. PAUL ISLAND, ALASKA
DESIGN FOR WAVE AND SHOALING PROTECTION

Coastal Model Investigation

PART I: INTRODUCTION

Prototype

1. St. Paul Island is the northernmost and largest island of the Pribilofs, located in the southeastern Bering Sea (Figure 1). The Pribilofs are of volcanic origin, and St. Paul Island is composed predominantly of volcanic materials in the form of lava flows and loose cinders with sandy deposits. The west and southwest portions of the island are relatively high and mountainous with precipitous cliffs along the coast. The remainder of the island is relatively low and rolling with a number of extinct volcanic peaks scattered throughout.

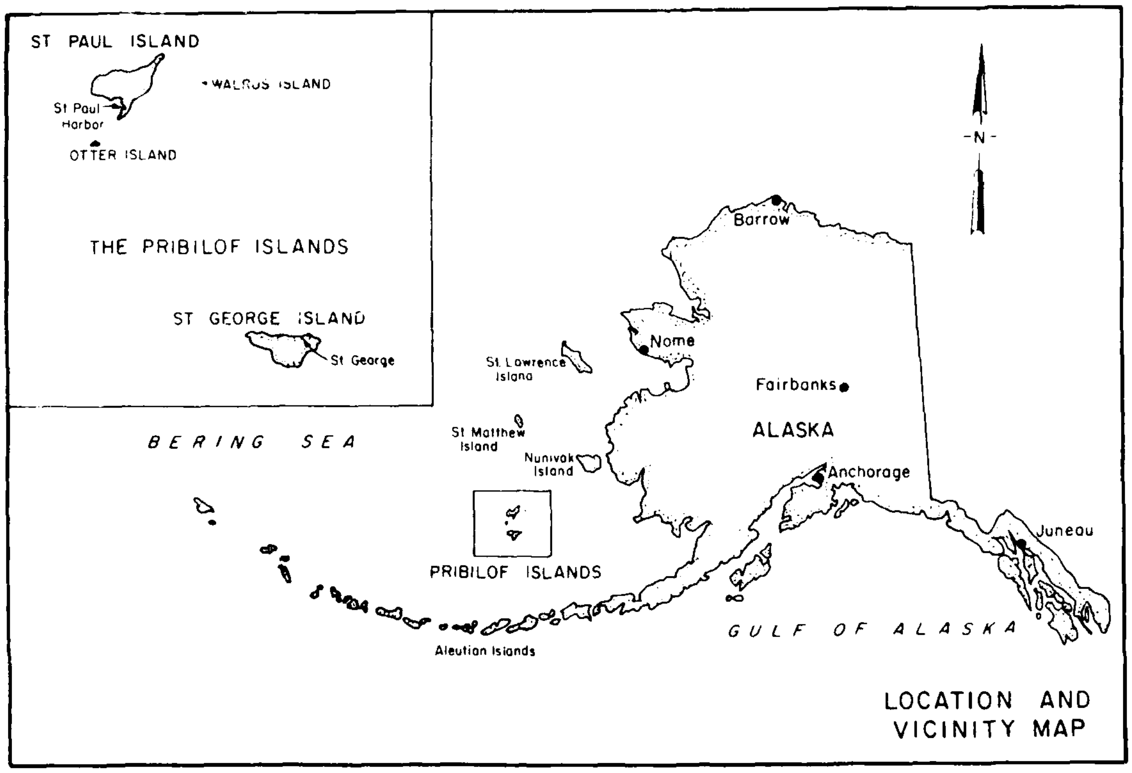

Figure 1. Project location

2. The Pribilof Islands support large populations of birds, mammals, fish, and invertebrates. The Pribilofs are the primary breeding ground for northern fur seals where approximately two-thirds of the world's population (1.3 to 1.4 million) migrate annually (US Army Engineer District (USAED), Alaska (USAED, Alaska, 1981). More than a quarter of a million seabirds nest on St. Paul Island each year, mainly along the coastal cliffs. The uplands are inhabited by songbirds, white and blue foxes, and a transplanted herd of approximately 250 reindeer. The island is treeless and covered with grasses, sedges, and wildflowers. The eastern Bering Sea near St. Paul supports populations of shrimp and five commercially harvestable species of crab. Surveys by the National Marine Fisheries Service (NMFS) indicate tremendous potential for the bottom fish industry in the area. The eastern Bering shelf could produce an annual harvest of over 3 billion pounds* of marine products, (USAED, Alaska, 1981).

3. The city of St. Paul is located on a cove on the southern tip of the island and is the island's only settlement with a population of approximately 600. Most inhabitants of the island are Aleuts, natives of the Aleutian Islands of Alaska. The islands were originally settled by the Russians to harvest fur seals. The treaty for the purchase of Alaska from Russia by the United States in 1867 placed the Pribilofs under United States control. The NMFS and its predecessor Federal agencies have been responsible for the fur seal industry in the Pribilofs since 1911, managing the harvest according to a series of international agreements between the United States, Canada, Japan, and the Soviet Union.

Problems and Needs

4. The economy of the community of St. Paul and the Pribilof Islands has been dominated by the fur seal industry since settlement by the Russians. The harvest of fur seals in the Pribilofs has recently been discontinued due to a seal harvest moratorium. This event has had a significant adverse impact on the economy of St. Paul. Clearly, the standard of living cannot be maintained due to the moratorium. There is a critical need for new sources of employment and income.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

5. Since St. Paul Island is situated logistically at the center of the largest fisheries resources in the United States, the construction of a harbor is being considered as an alternative economic source. The increase of commercial fishing for crab and bottom fish by US vessels in this part of the Bering Sea has been accompanied by a growing need for a harbor and a nearby source of essential services to reduce the hazards and inefficiency of exploitation of this valuable food resource.

6. Ocean freight service to St. Paul Island is vital. Present delays and resultant high costs of ocean freight service are increasingly hard for the locals to bear. The recreation and subsistence fishing activities of the St. Paul Aleuts are an integral part of their cultural heritage and are made difficult and dangerous by the lack of a secure harbor on the island.

7. The establishment of marine related industry in the eastern Bering Sea at St. Paul Island would fulfill the following significant needs of the area:

- a. Maintain the existing cultural and environmental resources of St. Paul Island and the eastern Bering Sea.
- b. Reduce operating cost of US commercial fishing, subsistence fishing, and other vessels operating near St. Paul Island in the eastern Bering Sea.
- c. Increase the harvest of marine resources by US vessels in the eastern Bering Sea.
- d. Reduce the cost of ocean freight service to St. Paul Island.

Existing Breakwater

8. A breakwater was constructed at the site in Village Cove during the early 1980's (Figure 2) but subsequently failed during storms of 1984. A new structure was designed and construction was completed in 1985 by Tetra Tech, Inc., consultants to the City of St. Paul (Tetra Tech, Inc. 1987). This breakwater is presently 750 ft in length and has functioned well, in regard to stability, during the 1985 and 1986 winter seasons. A 200-ft-long, vertical-wall dock was installed in the lee of the breakwater in 1986 to accommodate fishing vessels with a maximum draft of 18 ft.

9. The existing breakwater is not of sufficient length to provide wave protection to vessels utilizing the dock, particularly during storm events. Additionally, since construction of the new structure, scouring of an area

Figure 2. Aerial view of St. Paul Harbor

seaward of the breakwater head has occurred. Accretion of sediment along the southeast shoreline of Village Cove is also apparent. Based on bathymetric surveys since breakwater construction, it appears the movement of this sediment is occurring during the winter storm season.

Purpose of Model Study

10. At the request of the US Army Engineer District, Alaska (NPA), a coastal hydraulic model investigation was initiated by the US Army Engineer Waterways Experiment Station's (WES) Coastal Engineering Research Center (CERC) to:

- a. Study wave and shoaling conditions for the existing harbor.
- b. Determine the most economical breakwater extension configuration that would provide adequate wave protection to the proposed mooring area and docking facilities.
- c. Provide qualitative information on the effects of the breakwater extension on sediment movement adjacent to the harbor and shoreline of Village Cove.
- d. Develop remedial plans for the alleviation of undesirable conditions as necessary.

A stability study was conducted for selection of the optimum breakwater cross section and is reported separately (Ward, in preparation).

Wave Height Criteria

11. Completely reliable criteria have not yet been developed for ensuring satisfactory navigation and mooring conditions for 80- to 130-ft fishing vessels in small-craft harbors during attack by waves. For this study, however, NPA specified initially that for an improvement plan to be acceptable, maximum wave heights were not to exceed 2.5 ft along the dock. During the course of the investigation, however, it was determined that wave heights along the dock could be relaxed slightly provided that maximum wave heights in a specified mooring area did not exceed the 2.5-ft criteria. This was determined at a meeting at WES attended by representatives of Headquarters, US Army Corps of Engineers, US Army Engineer Division North Pacific, NPA, CERC, and the City of St. Paul, Alaska, and their consultants, Tetra Tech, Inc.

PART II: THE MODEL

Design of Model

12. The St. Paul Harbor model (Figure 3) was constructed to an undistorted linear scale of 1:75, model to prototype. Scale selection was based on such factors as:

- a. Depth of water required in the model to prevent excessive bottom friction.
- b. Absolute size of model waves.
- c. Available shelter dimensions and area required for model construction.
- d. Efficiency of model operation.
- e. Available wave-generating and wave-measuring equipment.
- f. Model construction costs.

A geometrically undistorted model was necessary to ensure accurate reproduction of short-period wave and current patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law (Stevens 1942). The scale relations used for design and operation of the model were as follows:

Characteristic	Dimension*	Scale Relations Model:Prototype
Length	L	$L_r = 1:75$
Area	L^2	$A_r = L_r^2 = 1:5,625$
Volume	L^3	$\bar{V}_r = L_r^3 = 1:421,875$
Time	T	$T = L_r^{1/2} = 1:8.66$
Velocity	L/T	$V_r = L_r^{1/2} = 1:8.66$

* Dimensions are in terms of length and time.

13. The proposed plans for St. Paul Harbor included the use of rubble-mound structures and the existing breakwater is also a rubble-mound structure. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type structure; thus, the transmission

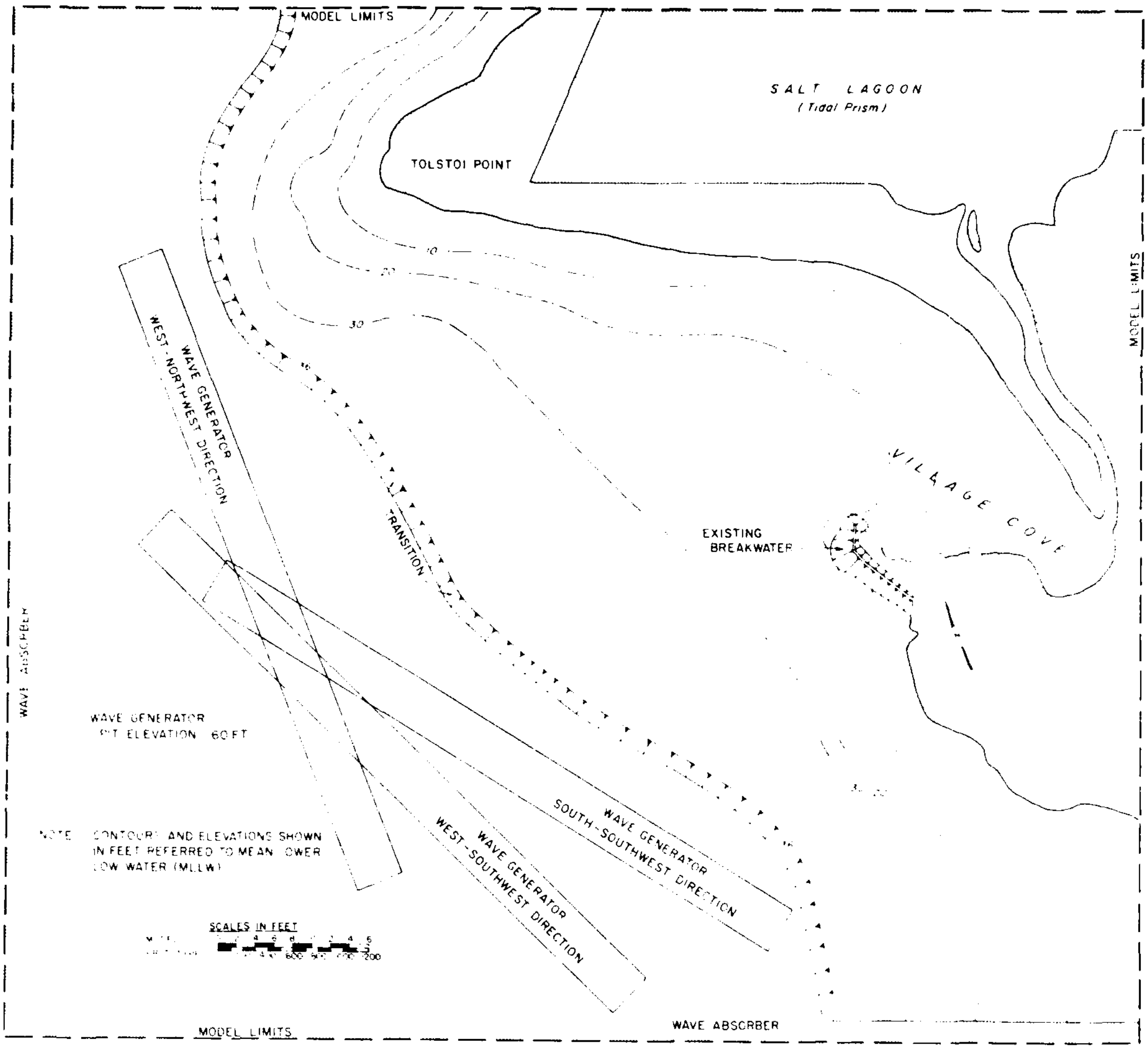

Figure 3. Model layout

and absorption of wave energy became a matter of concern in the 1:75-scale model design. In small-scale hydraulic models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than geometrically similar prototype structures (Le Méhauté 1965). Also, the transmission of wave energy through a rubble-mound structure is relatively less for the small-scale model than for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure satisfactory reproduction of wave-reflection and wave-transmission characteristics. In past investigations (Dai and Jackson 1966, Brasfeild and Ball 1967) at WES, this adjustment was made by determining the wave-energy

transmission characteristics of the proposed structure in a two-dimensional (2-D) model using a scale large enough to ensure negligible scale effects. A section then was developed for the small-scale, three-dimensional (3-D) model that would provide essentially the same relative transmission of wave energy. Therefore, from previous findings for structures and wave conditions similar to those at St. Paul, it was determined that a close approximation of the correct wave-energy transmission characteristics would be obtained by increasing the size of the rock used in the 1:75-scale model to approximately 1-1/2 times that required for geometric similarity. Accordingly, in constructing the rubble-mound structures in the St. Paul Harbor model, the rock sizes were computed linearly by scale, then multiplied by 1.5 to determine the actual sizes to be used in the model.

14. Ideally, a quantitative, 3-D, movable-bed model investigation would best determine the impacts of the proposed structures with regard to the deposition of sediment throughout the harbor. However, this type of model investigation is difficult and expensive to conduct, and each area in which such an investigation is contemplated must be carefully analyzed. In view of the complexities involved in conducting movable-bed model studies, and due to limited funds and time for the St. Paul Harbor project, the model was molded in cement mortar (fixed-bed) at an undistorted scale of 1:75 and a tracer material was obtained to qualitatively determine shoaling in the harbor for existing conditions and some of the improvement plans.

Model and Appurtenances

15. The model reproduced approximately 13,500 ft of the St. Paul Island shoreline and included the existing harbor (located in Village Cove), and underwater topography in the Bering Sea to an offshore depth of 36 ft with a sloping transition to the wave generation pit elevation of -60 ft. A small connecting channel to a salt lagoon (located east of the harbor) was also included in the model as well as the tidal prism of the salt lagoon. The total area reproduced in the model was approximately 16,100 sq ft, representing about 3.2 square miles in the prototype. A general view of the model is shown in Figure 4. Vertical control for model construction was based on

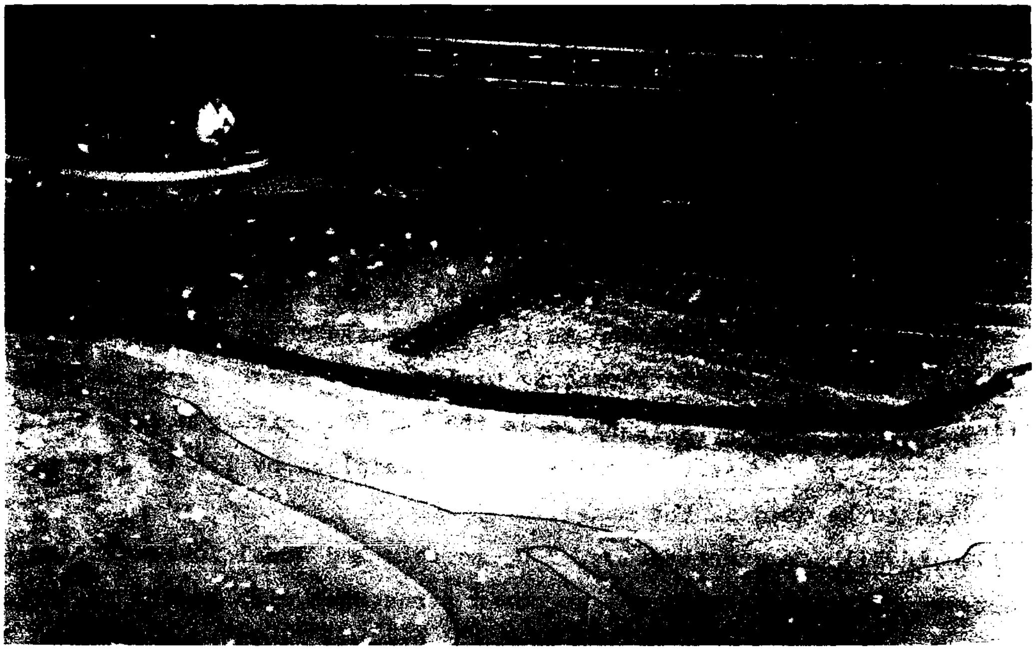

Figure 4. General view of model

mean lower low water (mllw).* Horizontal control was referenced to a local prototype grid system.

16. Model waves were generated by a 60-ft-long, unidirectional spectral, electrohydraulic, wave generator with a trapezoidal-shaped, vertical-motion plunger. The wave generator utilized a hydraulic power supply. The vertical motion of the plunger was controlled by a computer-generated command signal, and the movement of the plunger caused a periodic displacement of water which generated the required test waves. The wave generator also was mounted on retractable casters which enabled it to be positioned to generate waves from the required directions.

17. An Automated Data Acquisition and Control System (ADACS), designed and constructed at WES (Figure 5), was used to generate and transmit control signals, monitor wave generator feedback, and secure and analyze wave height data at selected locations in the model. Basically, through the use of a computer, ADACS recorded onto magnetic discs the electrical output of parallel-wire, resistance-type wave gages that measured the change in

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* All elevations (el) cited herein are in feet referred to mean lower low water (mllw), unless otherwise defined.

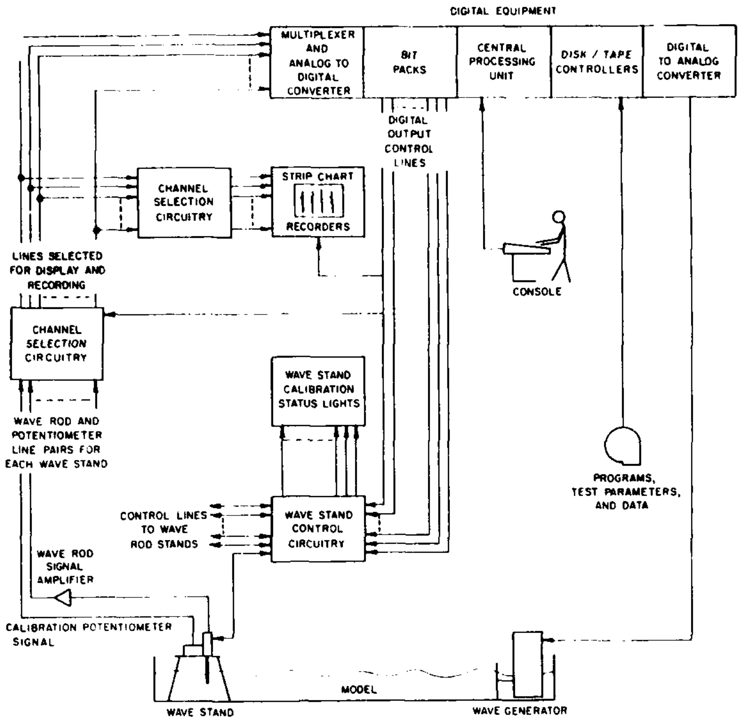


Figure 5. Automated Data Acquisition and Control System

water-surface elevation with respect to time. The magnetic disc output of ADACS was then analyzed to obtain the wave-height data.

18. A 2-ft (horizontal) solid layer of fiber wave absorber was placed around the inside perimeter of the model to dampen any wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

Selection of Tracer Material

19. As discussed in paragraph 14, a fixed-bed model was constructed and a tracer material selected to qualitatively determine the deposition of sediment in the harbor area. The tracer was chosen in accordance with the scaling relations of Noda (1972), which indicate a relation or model law among the four basic scale ratios, i.e. the horizontal scale, λ ; the vertical scale, μ ; the sediment size ratio, i.e. η_D ; and the relative specific weight ratio, η_γ (Figure 6). These relations were determined experimentally using

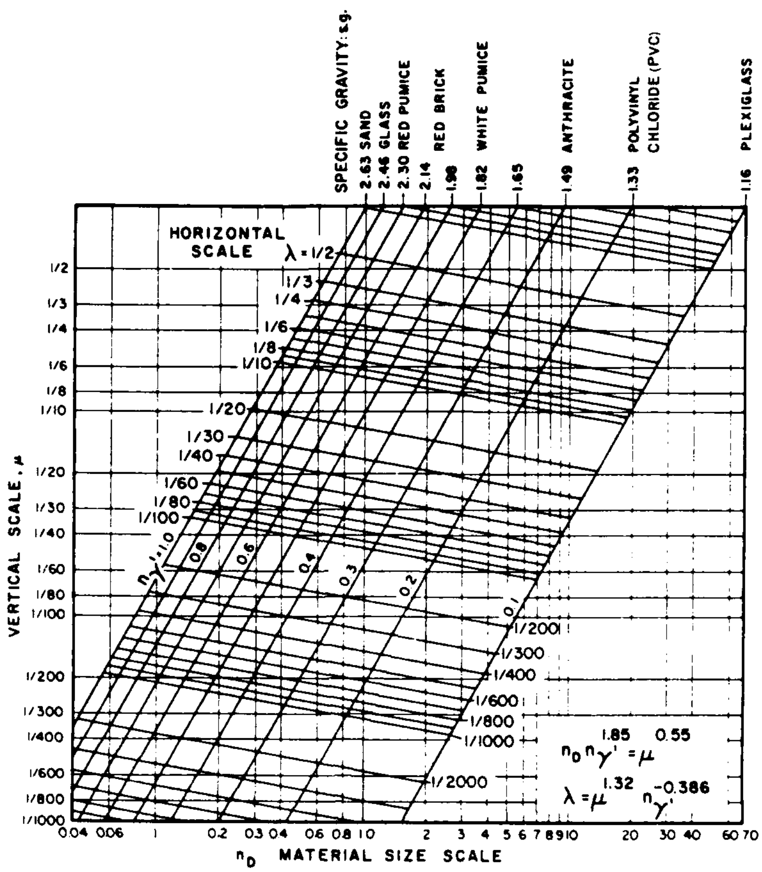


Figure 6. Graphic representation of model law (from Noda 1972)

a wide range of wave conditions and bottom materials and are valid mainly for the breaker zone.

20. Noda's scaling relations indicate that movable-bed models with scales in the vicinity of 1:75 (model to prototype) should be distorted (i.e., they should have different horizontal and vertical scales). Since the fixed-bed model of St. Paul Harbor was undistorted to allow accurate reproduction of short-period wave and current patterns, the following procedure was used to select a tracer material. Using the prototype sand characteristics (median diameter, D_{50} = 0.19 mm, specific gravity = 2.82) and assuming the horizontal scale to be in similitude (i.e. 1:75), the median diameter for a given specific gravity of tracer material and the vertical scale were computed. The vertical scale was then assumed to be in similitude and the tracer median diameter and horizontal scale were computed. This resulted in a range of

tracer sizes for given specific gravities that could be used. Although several types of movable-bed tracer materials were available at WES, previous investigations (Giles and Chatham 1974, Bottin and Chatham 1975) indicated that crushed coal tracer more nearly represented the movement of prototype sand. Therefore, quantities of crushed coal (specific gravity = 1.30; median diameter, D_{50} = 0.64 mm) were selected for use as a tracer material.

PART III: TEST CONDITIONS AND PROCEDURES

Selection of Test Conditions

Still-water level

21. Still-water levels (swl's) for harbor wave action models are selected so that the various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. These phenomena include the refraction of waves in the project area, the overtopping of harbor structures by the waves, the reflection of wave energy from various structures, and the transmission of wave energy through porous structures.

22. In most cases, it is desirable to select a model swl that closely approximates the higher water stages which normally occur in the prototype for the following reasons:

- a. The maximum amount of wave energy reaching a coastal area normally occurs during the higher water phase of the local tidal cycle.
- b. Most storms moving onshore are characteristically accompanied by a higher water level due to wind tide and shoreward mass transport.
- c. The selection of a high swl helps minimize model scale effects due to viscous bottom friction.
- d. When a high swl is selected, a model investigation tends to yield more conservative results.

23. Swl's of +3.2 and +5.0 ft were selected by NPA for use during model testing. The lower value (+3.2 ft) represents mean higher high water (mhhw) and was used during the conduct of tracer tests and while obtaining wave-induced current patterns and magnitudes. The higher value (+5.0 ft) was used when securing wave height data and wave-pattern photographs. It represents mhhw (+3.2 ft) with a 1.8 ft rise in local water level due to atmospheric pressure depression, storm surge, and wave set-up combined. A +5.0 ft swl has also been estimated, based on observations made during storms at St. Paul Harbor (Tetra Tech 1987).

Factors influencing selection of test wave characteristics

24. In planning the testing program for a model investigation of harbor wave-action problems, it is necessary to select dimensions and directions for the test waves that will allow a realistic test of proposed improvement plans

and an accurate evaluation of the elements of the various proposals. Surface-wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum wave that can be generated by a given storm depend on the wind speed, the length of time that wind of a given speed continues to blow, and the water distance (fetch) over which the wind blows. Selection of test wave conditions entails evaluation of such factors as:

a. The fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can attack the problem area.

b. The frequency of occurrence and duration of storm winds from the different directions.

c. The alignment, size, and relative geographic position of the navigation entrance to the harbor.

d. The alignments, lengths, and locations of the various reflecting surfaces inside the harbor.

e. The refraction of waves caused by differentials in depth in the area seaward of the harbor, which may create either a concentration or a diffusion of wave energy at the harbor site.

Wave refraction

25. When wind waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order of approximation). The most important transformations with respect to the selection of test wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. The change in wave height and direction may be determined by using the numerical Regional Coastal Processes Wave Transformation Model (RCPWAVE) developed by Ebersole (1985). This model predicts the transformation of monochromatic waves over complex bathymetry and includes refractive and diffractive effects. Diffraction becomes increasingly important in regions with complex bathymetry. Finite difference approximations are used to solve the governing equations and the solution is obtained for a finite number of grid cells which comprise the domain of interest. Much of the early work in this area during the 1950's, was based on wave ray methods and manual construction of refraction diagrams using linear, gravity wave theory. During the 1960's and early 1970's, the linear wave refraction problem was solved in a more

efficient way through the use of the digital computer. All of these methods, however, addressed the refraction problem only.

26. The solution technique employed by RCPWAVE is a finite difference approach; thus, the wave climate in terms of wave height H, wave period T, and wave direction-of-approach θ, is available at a large number of computational points throughout the region of interest, and not just along wave rays. Computationally, the model is very efficient for modeling large areas of coastline subjected to widely varying wave conditions and, therefore, is an extremely useful tool in the solution of many types of coastal engineering problems.

27. When the refraction coefficient K_r is determined, it is multiplied by the shoaling coefficient K_s and gives a conversion factor for transfer of deepwater wave heights to shallow-water values. The shoaling coefficient, a function of wave length and water depth, can be obtained from the Shore Protection Manual (1984).

28. Refractive-diffractive effects for St. Paul Harbor were produced from a rectangular-depth grid (12.1 × 10.2 miles) which extended into the Bering Sea to the south and west of St. Paul Island (directions from which storm waves approach the harbor). Limits of the depth grid used are shown in Figure 7. Grid spacing was 500 ft and depths were taken from the latest National Oceanic and Atmospheric Administration (NOAA) charts. Storm conditions were represented by superimposing a water level of 5.0 ft on the depth grid.

29. Refraction and shoaling coefficients and shallow-water directions were obtained at St. Paul for various wave periods from five deepwater wave directions (west-northwest counterclockwise through south-southwest), and are presented in Table 1. Shallow-water wave directions and refraction coefficients represent an average of the values in the immediate vicinity of the harbor site (approximately the location of the wave generator in the model). Shoaling coefficients were computed for a 65-ft water depth (60-ft pit elevation with 5-ft tide conditions superimposed) corresponding to the simulated depth at the model wave generator. The wave height adjustment factor, $K_r \times K_s$, can be applied to any deepwater wave height to obtain the corresponding shallow-water value. Based on the refracted directions secured at the approximate locations of the wave generator in the model for each wave period, the following test directions (deepwater direction and corresponding

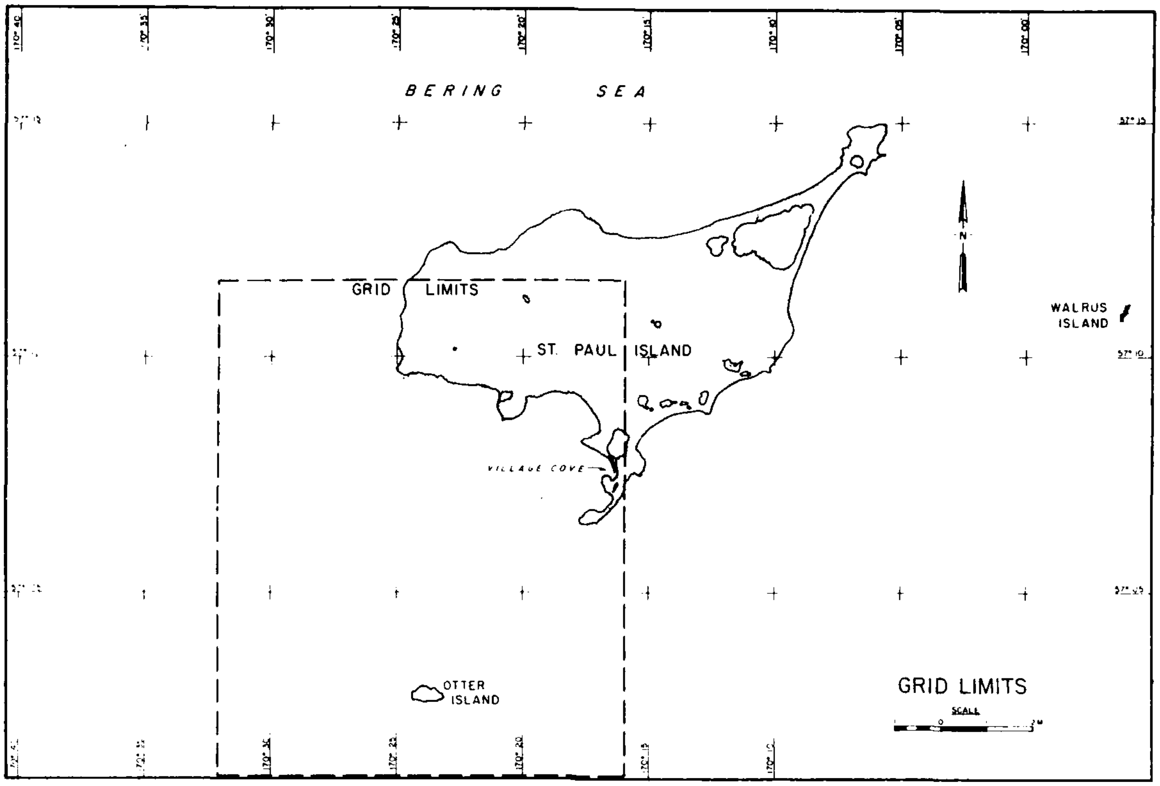


Figure 7. Wave refraction grid limits

shallow-water direction) were selected for use during model testing:

Deepwater Direction Azimuth, deg	Selected Shallow-Water Test Direction, Azimuth, deg
West-northwest, 292.5	269
West, 270	259
West-southwest, 247.5	245
Southwest, 225	233
South-southwest, 202.5	231

The shallow-water wave directions were taken to be the average directions of the refracted waves for the significant wave periods noted from each deepwater direction.

Prototype wave data and selection of test waves

30. Measured prototype wave data on which a comprehensive statistical analysis of wave conditions could be based were unavailable for the St. Paul

Harbor area. However, statistical deepwater wave hindcast data representative of this area were obtained from the CERC Wave Information Studies (WIS). More information on WIS may be obtained from Corson (1985). Deepwater WIS data (obtained at coordinates; 55.54° N, 170.65° W) are summarized in Table 2. These data were converted to shallow-water values by application of refraction and shoaling coefficients and are shown in Table 3. Characteristics of test waves used in the model (selected from Table 3) are shown in the following tabulation:

	Selected Test Waves	
Deepwater Direction	Period, sec	Height, ft
West-northwest	6	7
	8	7
	10	7,13
	12	7,13
	14	10,16
	16	16,19
West	6	10
	8	10
	10	10,19
	12	16,19
	14	16
	16	19
West-southwest	6	10
	8	10,16
	10	10,25
	12	16,19
	14	16
	16	19
Southwest	6	10
	8	7,13
	10	7,16
	12	10,19
	14	16
	16	19
South-southwest	6	7
	8	7,13
	10	7,19
	12	7,16
	14	10,16
	16	16

Unidirectional wave spectra for the selected test waves listed above (based on wave conditions (JONSWAP) parameters) were generated and used throughout the

model investigation. Plots of typical wave spectra are shown in Figure 8. The dashed line represents the desired spectra while the solid line represents the spectra generated by the wave generator. A typical wave train time-history also is shown in Figure 9.

Analysis of Model Data

31. Relative merits of the various plans tested were evaluated by:

- a. Comparison of wave heights at selected locations in the model.
- b. Comparison of sediment tracer movement and subsequent deposits.
- c. Visual observations and wave-pattern photographs.

In the wave height data analysis, the average height of the highest one-third of the waves recorded at each gage location was computed. All wave heights were then adjusted to compensate for excessive model wave height attenuation due to viscous bottom friction by application of Keulegan's equation (Keulegan 1950).* From this equation, reduction of wave heights in the model (relative to the prototype) can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel.

* G. H. Keulegan. 1950 (May). "The Gradual Damping of a Progressive Oscillatory Wave with Distane in a Prismatic Rectangular Channel," National Bureau of Standards, Washington, DC.

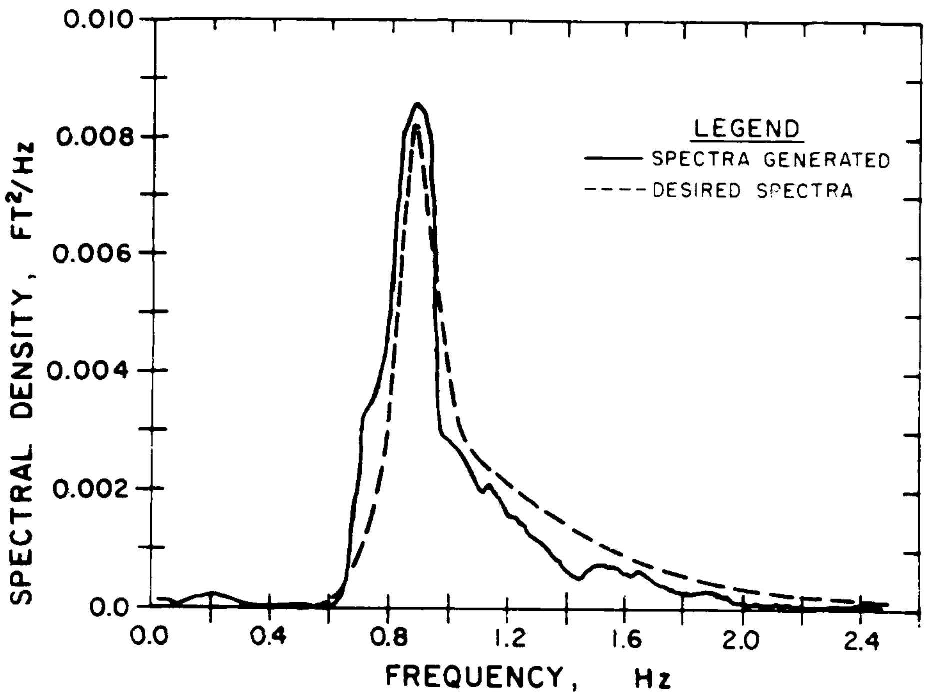


Figure 8. Typical wave-spectra plot, 10-sec, 16-ft test waves

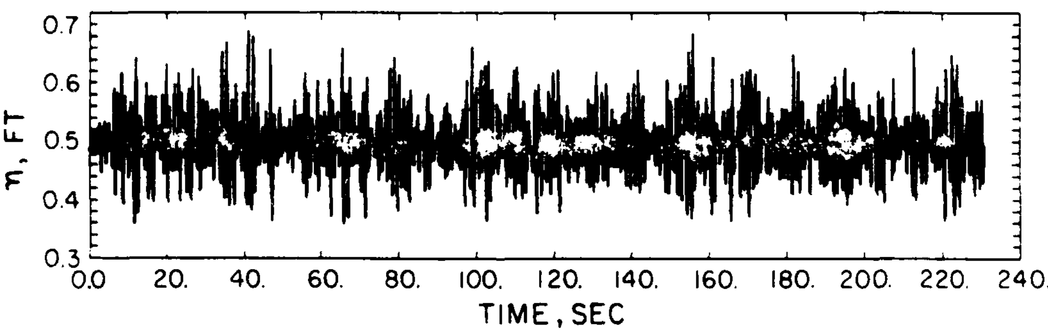


Figure 9. Typical wave train time-history, 10-sec, 16-ft test waves

PART IV: TESTS AND RESULTS

Tests

Existing conditions

32. Prior to testing of the various improvement plans, comprehensive tests were conducted for existing conditions (Plate 1). Wave height data were obtained in the harbor and along the center line of the proposed breakwater extension (for design wave information) for the selected test waves and directions listed in paragraph 30. Sediment tracer patterns, wave-induced current patterns and magnitudes, and wave-pattern photographs were also secured for representative test waves from the five test directions.

Improvement plans

33. Wave heights and wave patterns were secured for 59 test plan configurations. Variations entailed changes in lengths, alignments, and crest elevations of breakwater extensions, breakwater spurs, and a secondary breakwater. Wave-induced current patterns and magnitudes, tracer patterns, and videotape footage were obtained for representative test waves for some of the improvement plans. Brief descriptions of the improvement plans are presented in the following subparagraphs; dimensional details are presented in Plates 2-32.

a. Plan 1 (Plate 2) consisted of a 1,050-ft-long extension of the existing breakwater and an 800-ft dock extension. The crest elevation of the breakwater extension was +30 ft and the elevation of the top of the dock was +12 ft. The seaward slope of the trunk of the breakwater extension was 1V:2H, and the harbor-side slope was 1V:1.5H. The head of the breakwater extension had side slopes of 1V:3H.

b. Plan 2 (Plate 3) entailed the elements of Plan 1 with a 100-ft-long spur originating at the northeast corner of the dock, and extending in an easterly direction perpendicular to the breakwater extension. An absorber (approximately 150 ft in length) was included on the northern face of the dock that extended from its northeast corner to the breakwater extension. The crest elevation of the spur and absorber was +12 ft and side slopes were 1V:1.5H. Seven- to ten-ton armor stone was used for the spur.

c. Plan 3 (Plate 3) included the elements of Plan 2 with an additional 100-ft-long extension of the breakwater spur.

d. Plan 4 (Plate 3) involved the elements of Plan 2 with an additional 200-ft-long extension of the breakwater spur.

e. Plan 5 (Plate 4) consisted of the elements of Plan 1 with an additional 1,400-ft-long low-crested, shore-connected secondary breakwater installed west of the original breakwater and dock extension. The shore-connected structure had an elevation of +6 ft, side slopes of 1V:1.5H, and a crest width of 40 ft. The low-crested breakwater was positioned to allow a 200-ft-wide navigation entrance. Seven- to ten-ton armor stone was used for this breakwater with core stone 6 ft above the bottom elevation.

f. Plan 6 (Plate 5) entailed the absorber and 100-ft-long spur of Plan 2 with 100 ft of structure removed from the seaward end of the low-crested breakwater of Plan 5.

g. Plan 7 (Plate 6) involved the absorber and 200-ft-long spur of Plan 3 with 200 ft of structure removed from the seaward end of the low-crested breakwater of Plan 5.

h. Plan 8 (Plate 7) included the elements of Plan 7, but the low-crested breakwater was extended seaward 200 ft in length to completely close the navigation entrance to the harbor.

i. Plan 9 (Plate 8) consisted of a breakwater and dock extension similar to Plan 1, but the breakwater was only extended 1,000 ft in length and the dock was extended 550 ft. The total breakwater length was 1,750 ft and the total dock length was 750 ft. Also included was a 240-ft-long spur, which originated 280 ft shoreward of the breakwater head and extended easterly perpendicular to the breakwater extension. The spur had a crest elevation of +20 ft with 1V:1.5H side slopes.

j. Plan 10 (Plate 8) entailed the elements of Plan 9 with a 100 ft extension of the breakwater spur.

k. Plan 11 (Plate 8) involved the elements of Plan 9 with a 200 ft extension of the breakwater spur.

l. Plan 12 (Plate 8) included the elements of Plan 9 with a 300 ft extension of the breakwater spur.

m. Plan 13 (Plate 9) entailed the elements of Plan 9 with a 550-ft-long, detached, low-crested breakwater (el +6 ft) installed east of the original breakwater and dock extension. The position of the detached breakwater resulted in a 300-ft-wide navigation entrance.

n. Plan 14 (Plate 10) included the elements of Plan 13, but the detached breakwater was extended westerly 100 ft in length, which resulted in a 200-ft-wide navigation channel.

o. Plan 15 (Plate 11) involved the elements of Plan 13, but the spur was extended easterly 100 ft in length resulting in a 200-ft-wide entrance.

p. Plan 16 (Plate 11) consisted of the elements of Plan 15, but the low-crested, detached breakwater was extended easterly and connected to shore.

q. Plan 17 (Plate 12) included the elements of Plan 16, but the low-crested secondary breakwater's crest elevation was raised from +6 ft to +9 ft.

r. Plan 18 (Plate 12) involved the elements of Plan 17, but the secondary breakwater was extended 50 ft westerly resulting in a 150-ft-wide entrance.

s. Plan 19 (Plate 13) consisted of the elements of Plan 17, but the breakwater spur was extended easterly 50 ft resulting in a 150-ft-wide entrance.

t. Plan 20 (Plate 13) entailed the elements of Plan 19, but blocks were placed adjacent to the inside of the low-crested secondary breakwater resulting in an impervious structure.

u. Plan 21 (Plate 14) included the elements of Plan 19, but the breakwater spur was extended easterly 100 ft, and 100 ft of the western end of the secondary breakwater was removed. The entrance remained 150 ft in width.

v. Plan 22 (Plate 15) consisted of the Plan 9 breakwater and dock extension with the 100-ft-long spur extension of Plan 10. An additional 1,350-ft-long shore-connected secondary breakwater (el +15) was installed about 210 ft north of the original alignment and was positioned to provide a 300-ft-wide entrance between its toe and the toe of the breakwater extension.

w. Plan 23 (Plate 15) involved the elements of Plan 22 with 300 ft of the shore end of the secondary breakwater removed resulting in a 1,050-ft-long detached structure.

x. Plan 24 (Plate 16) entailed the elements of Plan 22, but the secondary breakwater was extended 100 ft westerly resulting in a 1,450-ft-long structure and a 200-ft-wide entrance.

y. Plan 25 (Plate 16) included the elements of Plan 22 with the secondary breakwater extended 50 ft westerly resulting in a 1,400-ft-long structure and a 250-ft-wide entrance.

z. Plan 26 (Plate 17) entailed the elements of Plan 25 with a 50 ft easterly extension of the breakwater spur.

aa. Plan 27 (Plate 17) entailed the elements of Plan 26 with a 50 ft reduction in length of the secondary breakwater at its western end. This resulted in a 1,400-ft-long breakwater with a 300-ft-wide entrance.

bb. Plan 28 (Plate 18) consisted of the breakwater and dock extensions of Plan 9. A 440-ft-long spur, however, was included which originated 200 ft shoreward of the breakwater head and extended easterly perpendicular to the breakwater extension. A 1,150-ft-long shore-connected secondary breakwater (el +9 ft) also was installed and positioned to form a 200-ft-wide entrance into the harbor.

cc. Plan 29 (Plate 19) entailed the elements of Plan 28, but the secondary breakwater was reoriented. The westerly 200 ft of the breakwater remained and the rest of the structure was installed in a southerly direction. The length of the breakwater was 1,040 ft.

dd. Plan 30 (Plate 19) included the elements of Plan 29, but the secondary breakwater was extended to shore east of the existing boat ramp resulting in a breakwater length of 1,390 ft.

ee. Plan 31 (Plate 20) involved the elements of Plan 30, but the seaward end of the secondary breakwater was extended 100 ft and reoriented to maintain the 200-ft-wide entrance.

ff. Plan 32 (Plate 20) entailed the elements of Plan 30, but the spur was extended 50 ft and the outer 200 ft of the secondary breakwater was reoriented to maintain the 200-ft-wide entrance.

gg. Plan 33 (Plate 21) consisted of the elements of Plan 32 with a continuous absorber (7- to 10-ton stone) installed along the northern 800 ft of the vertical wall dock.

hh. Plan 34 (Plate 21) entailed the elements of Plan 32 with a discontinuous absorber (7- to 10-ton stone) installed between caissons along the outer 800 ft of the vertical-faced dock. Caissons were about 50 ft long and 22 ft in width. The absorber was placed in 30-ft gaps between the caissons.

ii. Plan 35 (Plate 22) consisted of the 1,750-ft-long main breakwater extension of Plan 9. Also included was a spur which originated 405 ft from the head of the breakwater extension and extended easterly approximately 390 ft (150 ft beyond the face of the dock). An additional 1,350-ft-long shore-connected, secondary breakwater was installed parallel to the alignment as for Plan 5 but 125 ft northerly, and was positioned to provide a 250-ft-wide entrance between its toe and the toe of the breakwater extension. The crest elevation of the spur and secondary breakwater was +15 ft and armor stone ranging from 7-10 tons was used.

jj. Plan 36 (Plate 22) entailed the elements of Plan 35, but 200 ft of the secondary breakwater was removed at its shoreward end resulting in a 1,150-ft-long structure.

kk. Plan 37 (Plate 22) involved the elements of Plan 36 with the installation of a rubble-mound absorber (acting as a wave dissipator) adjacent to the shore south of the detached breakwater. The mound was approximately 350 wide along the shore and extended seaward about 200 ft at an elevation of +5 ft with slopes of approximately 1V:10H to the existing bottom depths. Armor stone ranging from 7-10 tons was used for this structure.

ll. Plan 38 (Plate 23) included the elements of Plan 37 with 50 ft of the spur removed.

mm. Plan 39 (Plate 23) entailed the elements of Plan 38, but the detached breakwater was extended 50 ft at its head resulting in a 1,200-ft-long structure with a 200-ft-wide entrance.

nn. Plan 40 (Plate 24) consisted of the elements of Plan 39, but an additional 150 ft of the detached breakwater was removed from its shoreward end resulting in a 1,050-ft-long structure.

oo. Plan 41 (Plate 24) included the elements of Plan 40, but the rubble-mound absorber was extended seaward an additional 50 ft.

pp. Plan 42 (Plate 25) entailed the elements of Plan 41, but the detached breakwater was extended 50 ft shoreward resulting in a 1,100-ft-long structure.

qq. Plan 43 (Plate 25) involved the elements of Plan 42, but the spur and the detached breakwater were reconstructed to include impervious cores to an elevation of +10 ft.

rr. Plan 44 (Plate 26) consisted of a 1,050-ft-long extension of the original breakwater similar to Plan 1, but the vertical-faced dock was not included in the lee of the breakwater. The elevation of the initial 800 ft of the extension was +32 ft with the seaward end of the structure installed at an elevation of +30 ft. A 1,350-ft-long secondary breakwater (same alignment as Plan 5) that was positioned to maintain a 200-ft-wide entrance between its toe and the toe of the main breakwater extension was also included. The secondary breakwater had a +18 ft crest elevation with an impervious core constructed to an elevation of +10 ft. Five-ton armor stone was used on the structure.

ss. Plan 45 (Plate 26) entailed the elements of Plan 44 with 50 ft of the seaward end of the secondary breakwater removed which resulted in an entrance width of 250 ft.

tt. Plan 46 (Plate 26) involved the elements of Plan 44 with 100 ft of the seaward end of the secondary breakwater removed which resulted in an entrance width of 300 ft.

uu. Plan 47 (Plate 27) included the elements of Plan 45 with 200 ft of the shoreward end of the secondary breakwater removed resulting in a 1,100-ft-long structure.

vv. Plan 48 (Plate 27) entailed the elements of Plan 47 with a rubble-mound absorber installed similar to that of Plan 37.

ww. Plan 49 (Plate 27) consisted of the elements of Plan 48, but the rubble-mound absorber was extended seaward an additional 50 ft.

xx. Plan 50 (Plate 28) included the elements of Plan 47, but at a point 400 ft from the shore, the secondary breakwater was angled southward resulting in a 350-ft spur. The spur was installed at a +10 ft crest elevation with no core and was oriented to form a 200-ft opening at the shore.

yy. Plan 51 (Plate 28) entailed the elements of Plan 50, but the spur was installed at an elevation of +18 ft with a core at ele\ation +10 ft similar to the rest of the secondary breakwater.

zz. Plan 52 (Plate 29) involved the elements of Plan 51, but the spur on the shoreward end of the secondary breakwater was oriented toward the north.

aaa. Plan 53 (Plate 29) included the elements of Plan 47, but a 250-ft-long groin was installed south of the shoreward end of the secondary breakwater. The groin had a crest elevation of +18 ft with a core elevation of +10 ft, and 5-ton armor stone was used.

bbb. Plan 54 (Plate 30) entailed the elements of Plan 47, but an additional 100 ft of the shore end of the secondary breakwater was removed resulting in a 1,000-ft-long structure and a 300-ft opening.

ccc. Plan 55 (Plate 30) consisted of the elements of Plan 47 with a rubble-mound absorber installed on the shoreline south of the vertical faced dock. The absorber had a radius of 100 ft and an elevation of +5 ft with 1V:8H side slopes and was constructed of 5-ton stone.

ddd. Plan 56 (Plate 31) consisted of the elements of Plan 55 with a 50-ft extension of the outer breakwater and the 1,000-ft-long secondary breakwater length of Plan 54. This plan resulted in a 250-ft-wide entrance channel and a 300-ft opening at the shore end of the secondary breakwater.

eee. Plan 57 (Plate 31) entailed the elements of Plan 56, but the secondary breakwater was extended 100 ft shoreward resulting in a 200-ft opening.

fff. Plan 58 (Plate 31) included the elements of Plan 57, but 50 ft of the outer end of the secondary breakwater was removed which resulted in a 300-ft-wide entrance.

ggg. Plan 59 (Plate 32) consisted of the elements of Plan 57, but 250 ft of the seaward end of the outer breakwater was removed which resulted in a 1,600-ft-long structure. The entire secondary breakwater was moved southerly 200 ft on the same alignment.

Wave height tests and wave patterns

34. Wave heights and wave patterns for the various improvement plans were obtained for test waves from one or more of the directions listed in paragraph 30. Tests involving certain proposed improvement plans were limited to the most critical direction of wave approach (i.e. west-northwest). The more promising improvement plans were tested comprehensively for waves from all test directions. Wave-gage locations for each improvement plan are shown in Plates 2-32.

Sediment tracer tests

35. Sediment tracer tests were limited to the original breakwater and dock extension (Plan 1) and the most promising improvement plan (Plan 47) as determined by results of the wave height testing. Tracer material was introduced into the model along and seaward of the harbor entrance and subjected to a series of representative test waves from various directions.

Wave-induced current pattern and magnitude tests

36. Wave-induced current patterns and magnitudes were determined at selected locations by timing the progress of an injected dye tracer relative to a graduated scale placed on the model floor. These tests were conducted for the most promising improvement plan (Plan 47) for representative test waves from four test directions.

Videotape

37. Videotape footage of the St. Paul Harbor model was secured for the original breakwater and dock extension (Plan 1) and the most promising improvement plan (Plan 47) as determined by results of the other tests. Extensive footage was obtained using a dye tracer to determine wave-induced harbor circulation patterns for Plan 47.

Results

38. In evaluating test results, the relative merits of the various plans were based initially on an analysis of measured wave heights along the dock and in the proposed mooring areas. Model wave heights (significant wave height or $H_{1/3}$) were tabulated to show measured values at selected locations. The general movement of tracer material and subsequent deposits in the harbor were shown in photographs, with arrows superimposed to depict sediment movement patterns. Wave-induced current patterns and magnitudes were plotted in plates for the plan and wave condition tested.

Existing conditions

39. Results of wave-height tests conducted for existing conditions are presented in Table 4. Maximum wave heights were 21.6 ft along the center line of the proposed breakwater extension (Gage 9) for 12-sec, 19-ft test waves from west-southwest; 8.7 ft at the existing boat ramp (Gage 2) for 10-sec, 25-ft test waves from west-southwest; 10.1 ft along the existing dock (Gage 4)

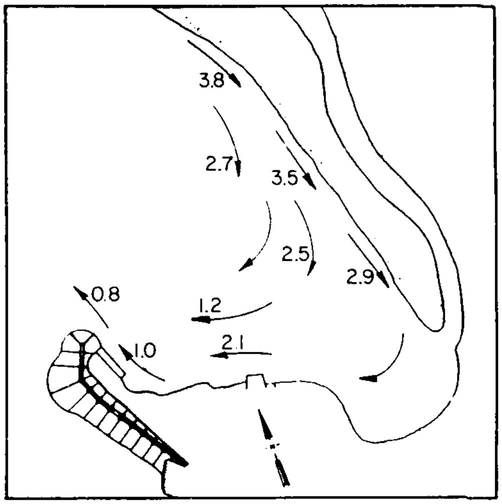
for 16-sec, 19-ft test waves from west and west-northwest; and 18.4 ft in the other harbor areas (Gage 6) for 12-sec, 19-ft test waves from west-southwest. Typical wave patterns for existing conditions are shown in Photos 1-10.

40. The general movement of tracer material and subsequent deposits for representative waves for existing conditions are shown in Photos 11-14 for the various directions. Sediment patterns in the harbor for each test series were similar for all test directions. Sediment in the eastern portion of the cove migrated southerly along the bolder spit toward the salt lagoon entrance. The larger test waves resulted in sediment material penetrating the bolder spit and depositing on the overbank between the bolders and the salt lagoon connecting channel. Sediment adjacent to the dock and breakwater head moved in a clockwise eddy in that vicinity for the larger test waves. Some material moved around and seaward of the head of the breakwater for test waves from west-northwest and west. Sediment tended to deposit in the lee of the dock for each test series for all directions.

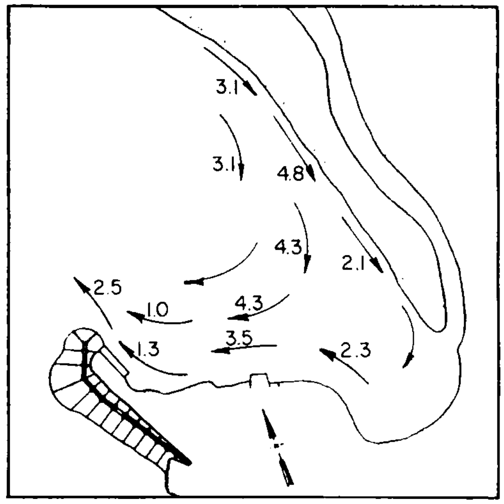
41. Wave-induced current patterns and magnitudes obtained for existing conditions for representative test waves and directions are shown in Figures 10-13. Maximum velocities obtained at various locations were as follows:

		Test Wave(s)		
Location	Maximum Velocity, fps	Period sec	Height ft	Direction
Shoreline along bolder spit	8.7	16	19	West-northwest
Area in cove westward of salt lagoon entrance channel	4.8	10	25	West-southwest
Shoreline adjacent to existing west dock	7.2	12	16	West
Area along dock and adjacent shoreline	6.2	10	25	West-southwest
Area along head of breakwater	4.8	12	19	West-southwest
Area in center of cove	5.4	10	19	West
		12	16	West

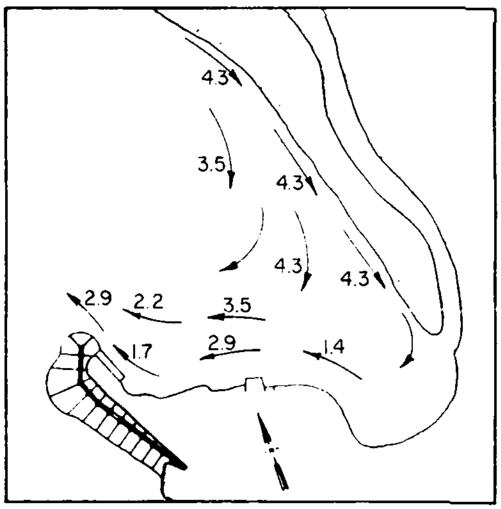
In general, currents in the cove moved in a clockwise direction for all test waves from all directions. They moved southerly along the bolder spit and seaward adjacent to the head of the breakwater. In some cases, a small counterclockwise eddy occurred west of the salt lagoon connecting channel entrance.



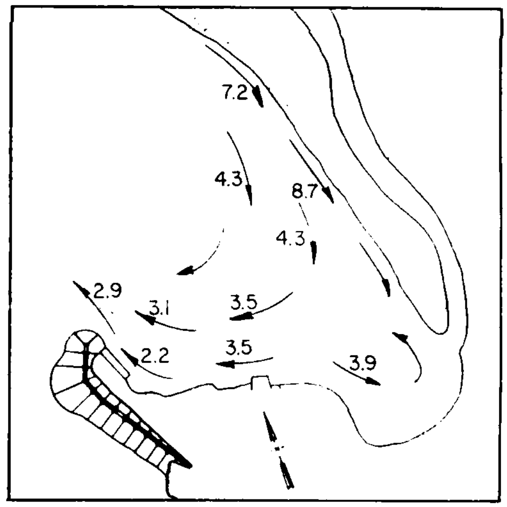
a. 8-sec, 7-ft test waves



b. 10-sec, 13-ft test waves

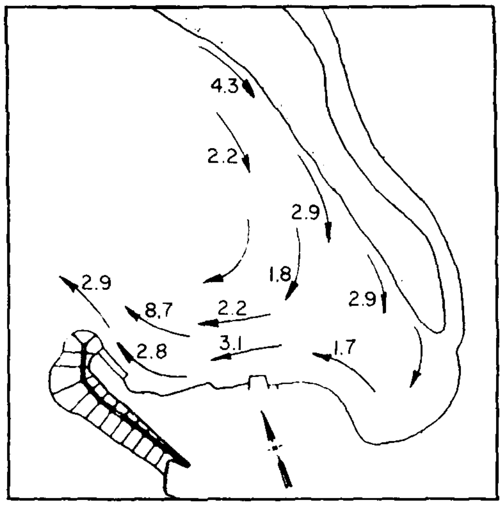


c. 14-sec, 16-ft test waves

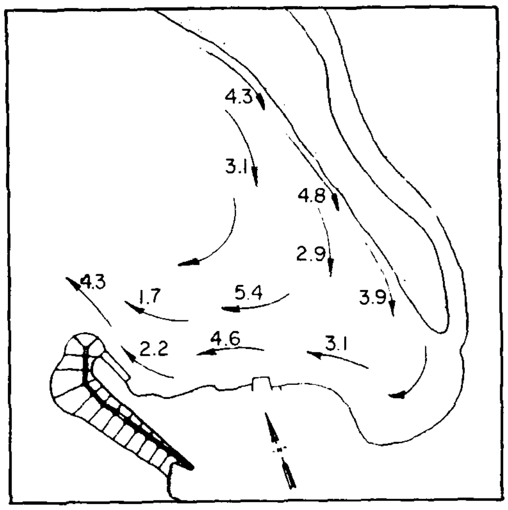


d. 16-sec, 19-ft test waves

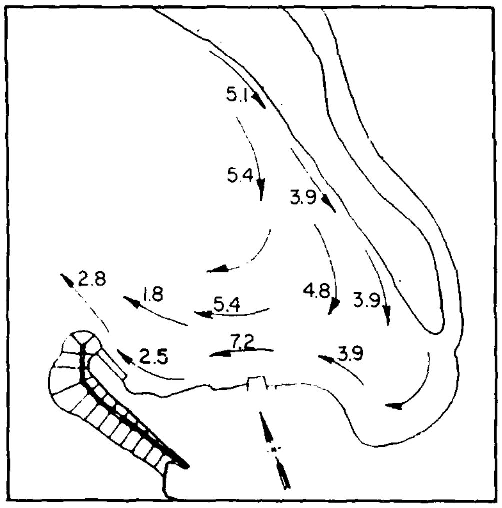
Figure 10. Typical current patterns and magnitudes (prototype feet per se‹ond) for existing conditions for test waves from west-northwest; swl = +3.2 ft



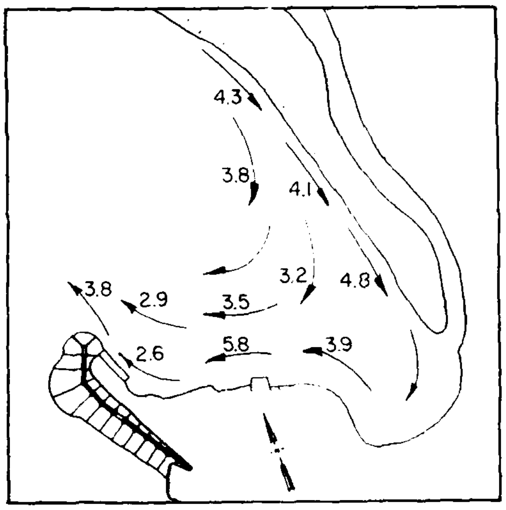
a. 6-sec, 10-ft test waves



b. 10-sec, 19-ft test waves

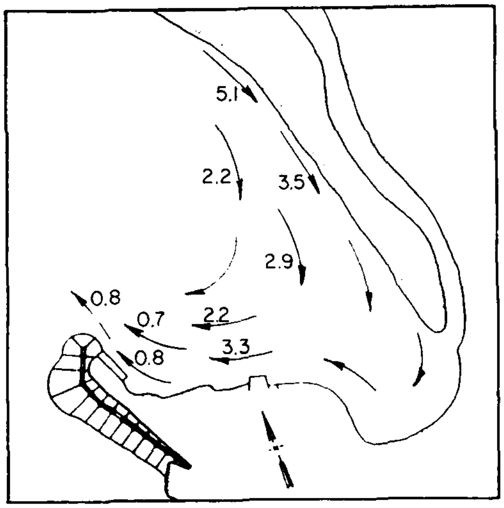


c. 12-sec, 16-ft test waves

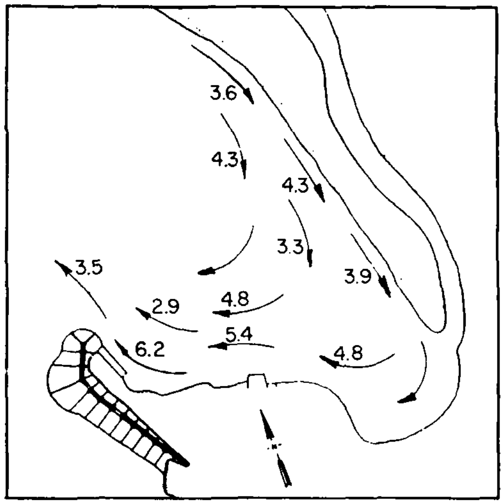


d. 16-sec, 19-ft test waves

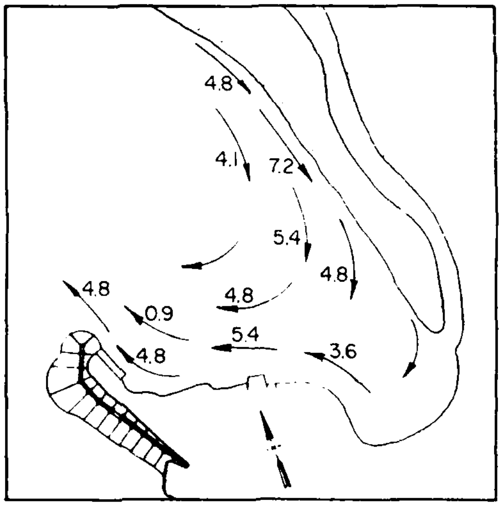
Figure 11. Typical current patterns and magnitudes (prototype feet per second) for existing conditions for test waves from west; swl = +3.2 ft



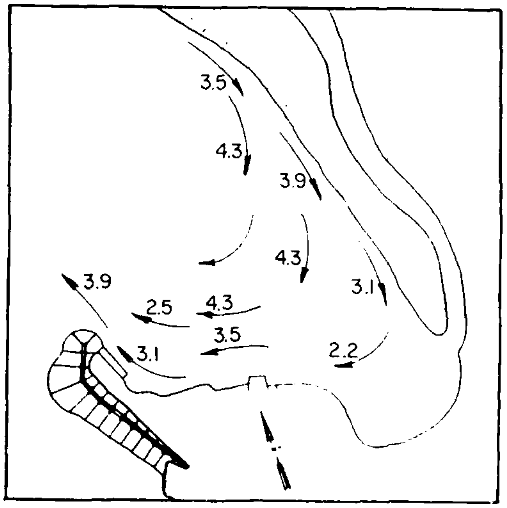
a. 6-sec, 10-ft test waves



b. 10-sec, 25-ft test waves

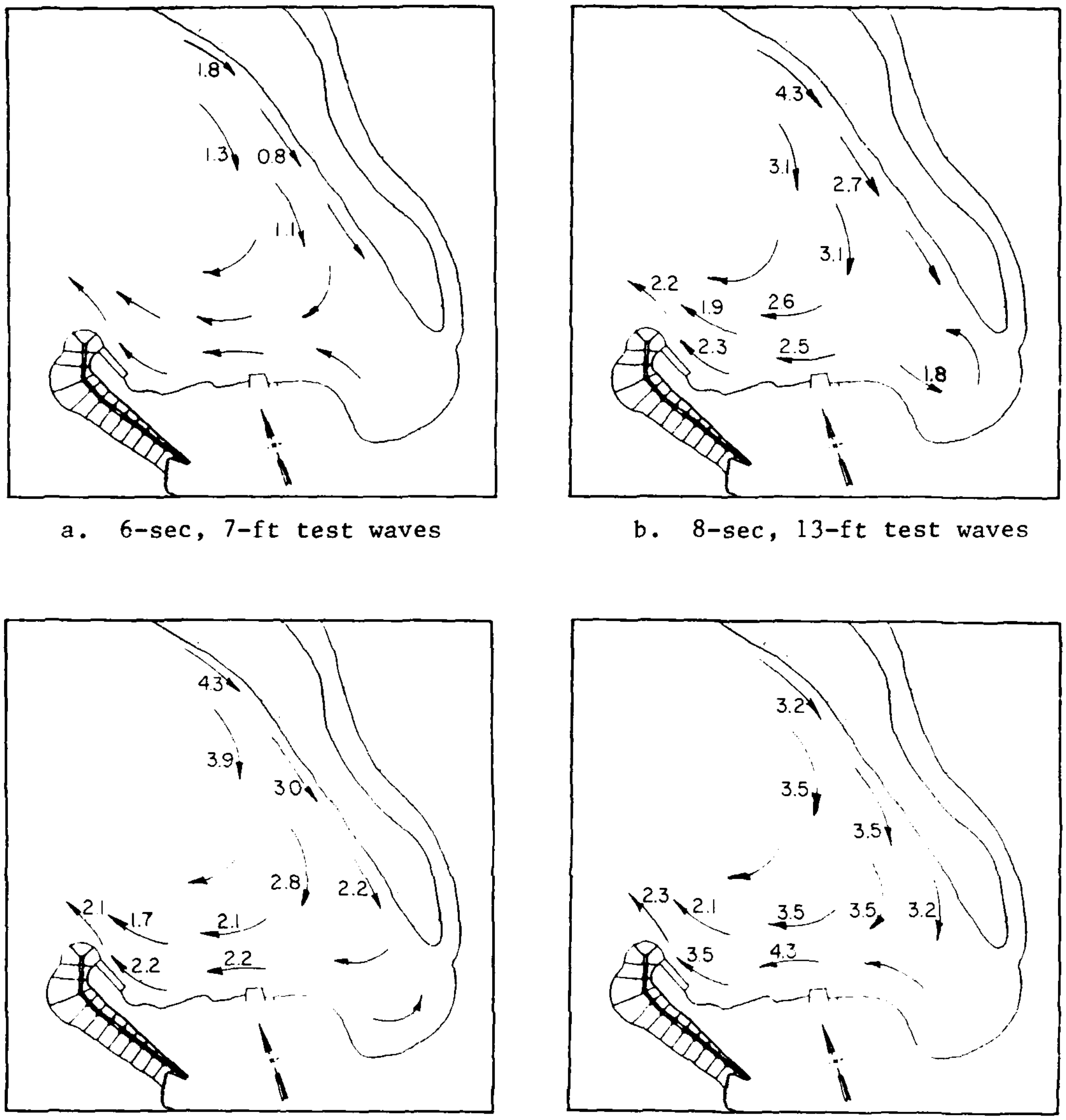


c. 12-sec, 19-ft test waves



d. 16-sec, 19-ft test waves

Figure 12. Typical current patterns and magnitudes (prototype feet per second) for existing conditions for test waves from west-southwest; swl = +3.2 ft



a. 6-sec, 7-ft test waves

b. 8-sec, 13-ft test waves

c. 10-sec, 19-ft test waves

d. 16-sec, 16-ft test waves

Figure 13. Typical current patterns and magnitudes (prototype feet per second) for existing conditions for test waves from south-southwest; swl = +3.2 ft

Improvement plans

42. Results of wave height tests conducted for Plan 1 are presented in Table 5. Maximum wave heights obtained were 6.8 ft along the vertical-wall dock (Gage 4) for 16-sec, 16-ft test waves from west-northwest and 10-sec, 25-ft test waves from west-southwest; 7.6 ft at the existing boat ramp (Gage 2) for 16-sec, 16-ft test waves from west-northwest; 9.2 ft along the center line of a proposed low-crested breakwater (Gage 13) for 16-sec, 16-ft test waves from west-northwest; and 6.0 ft in the other harbor areas (Gage 3) for 10-sec, 25-ft test waves from west-southwest. Maximum wave heights along the dock more than doubled the desired wave height criterion of 2.5 ft. Typical wave patterns for Plan 1 are shown in Photos 15-20.

43. The general movement of tracer material and subsequent deposits for representative test waves with Plan 1 installed are shown in Photos 21-23. Sediment patterns were similar for each test series from the various directions. Tracer in the eastern portion of the cove moved southerly adjacent to the bolder spit and settled in the cove. Sediment eastward of the head of the breakwater extension moved in a clockwise eddy. For test waves from west and west-northwest, some material moved seaward of the breakwater head for the larger test waves.

44. Wave height data obtained for Plans 2-4 are presented in Table 6 for representative test waves from west-northwest. Maximum wave heights were 6.0, 5.4, and 5.3 ft along the dock (Gages 4, 7-9) and 7.4, 7.7, and 7.6 ft in other areas of the harbor (Gages 3, 5, 6, 11-13) for Plans 2-4, respectively. Representative wave patterns for Plans 2-4 are shown in Photos 24-26.

45. Wave heights for Plans 5-8 are presented in Table 7. Maximum wave heights were 4.6, 3.6, 3.5, and 2.4 ft along the dock and 4.0, 3.3, 3.1, and 2.5 ft in the other harbor areas for Plans 5-8, respectively. Only the completely closed entrance of Plan 8 met the established wave height criterion of 2.5 ft. Typical wave patterns for Plans 5-8 are shown in Photos 27-30.

46. Results of wave height tests with Plans 9-12 installed are presented in Table 8. Maximum wave heights were 6.2, 5.6, 5.0, and 5.0 ft along the dock and 6.8, 6.3, 6.2, and 6.0 ft in other areas of the harbor for Plans 9-12, respectively. These test plans were ineffective in reducing wave heights to the 2.5-ft criterion. Typical wave patterns are shown in Photos 31-34 for Plans 9-12.

47. Wave height measurements secured for Plans 13-16 are presented in

Table 9. Maximum wave heights along the dock were 5.1, 4.9, 3.9, and 3.1 ft, and maximum wave heights in the other areas of the harbor were 5.5, 4.9, 4.9, and 3.4 ft, respectively, for Plans 13-16. This series of tests resulted in no test plans that met the established 2.5-ft criterion. Typical wave patterns for Plans 13-16 are shown in Photos 35-38.

48. Results of wave height tests with Plans 17-21 installed are presented in Table 10. Maximum wave heights along the dock were 3.1, 3.8, 3.3, 3.1, and 2.5 ft, and maximum wave heights in the other harbor areas were 3.4, 3.6, 3,3, 3.1, and 2.8 ft, respectively. Only Plan 21 met the 2.5-ft wave height criterion along the dock; however, the plan was not desirable due to the location of the navigation entrance. Representative wave patterns for Plans 17-21 are presented in Photos 39-43.

49. Wave heights obtained for Plans 22-27 are presented in Table 11. Maximum wave heights were 2.7, 3.2, 2.4, 2.7, 2.6, and 2.8 ft along the dock and 2.9, 4.2, 2.5, 2.7, 2.5, and 2.7 ft in the other areas of the harbor for Plans 22-27, respectively. Of this test series, only Plan 24 met the established wave height criteria along the dock and in the harbor area. Typical wave patterns for Plans 22-27 are shown in Photos 44-49.

50. Wave height data secured for Plans 28-34 are presented in Table 12. Maximum wave heights along the dock were 3.1, 3.7, 3.2, 2.7, 2.7, 2.7, and 2.6 ft; and maximum wave heights in the other harbor areas were 2.6, 3.1, 3.1, 2.8, 3.0, 2.9, and 2.9 ft, respectively, for Plans 28-34. This test plan series resulted in no plan meeting the established 2.5-ft wave height criterion. The navigation entrance into the harbor also was in an undesirable location. Wave patterns obtained for Plans 28-34 are shown in Photos 50-56.

51. At this point in the investigation, a conference was held at WES to review results of the various improvement plans tested to date. During the conference several expedited test plans (Plans 35-43) were installed and tested in the model. Wave height data secured for Plans 35-43 are presented in Table 13. Maximum wave heights obtained along the dock were 2.3, 2.6, 2.3, 2.8, 2.6, 2.8, 2.7, 2.6, and 2.5 ft; and maximum wave heights obtained in other harbor areas were 2.6, 3.1, 2.5, 2.9, 2.6, 2.9, 2.8, 2.8, and 2.6 ft for Plans 35-43, respectively. Typical wave patterns for Plans 35-43 are shown in Photos 57-65. Even though several of these test plans met the established criteria along the dock, it was determined that the entrance configuration was not optimal with regard to navigation. After further review of the results,

the following testing alternatives were agreed upon:

a. Future tests would be conducted without the vertical-faced dock. Construction plans would be changed to include a pile-supported dock instead.

b. A spur extending from the main breakwater extension would not be included in future tests since it would interfere with navigation of 250- to 350-ft-long vessels which call on St. Paul occasionally for resupply of fuel and commodities.

c. The 2.5-ft wave height criteria at the dock would be relaxed provided vessels could be moved to other designated areas in the harbor where the criteria could be met. An area in the lee of a proposed secondary breakwater was selected.

52. Results of wave height tests conducted for Plans 44-49 are shown in Table 14. Maximum wave heights along the proposed dock (Gages 4, 7-9) were 3.7, 3.3, 3.5, 4.1, 4.0, and 4.0, and maximum wave heights in the proposed mooring area (Gages 1, 11-13) were 2.1, 2.2, 2.6, 2.6, 2.5, and 2.5 ft for Plans 44-49, respectively. All of these plans met the newly established wave height criteria, with the exception of Plans 46 and 47, which only exceeded the criteria by one tenth of a foot. Representative wave patterns for Plans 44-49 are shown in Photos 66-71.

53. Wave height data secured for Plans 50-53 are shown in Table 15. Maximum wave heights were 4.1, 4.1, 3.9, and 3.7 ft along the proposed dock and 2.6, 2.6, 2.6, and 2.5 ft in the proposed mooring area for Plans 50-53, respectively. Only Plan 53 met the wave height criteria, but Plans 50-52 exceeded the criteria by only one-tenth of a foot. Typical wave patterns for Plans 50-53 are presented in Photos 72-75.

54. Wave height measurements obtained for Plans 54-59 are presented in Table 16. Maximum wave heights secured were 3.8, 4.0, 3.8, 3.7, 3.8, and 3.4 ft along the proposed dock and 2.7, 2.6, 2.6, 2.5, 2.7, and 2.7 ft in the proposed mooring area for Plans 54-59, respectively. Only Plan 57 met the established 2.5-ft wave height criterion, while Plans 55 and 56 exceeded the criteria by one-tenth of a foot. Representative wave patterns for Plans 54-59 are shown in Photos 76-81.

55. After an evaluation of the test results for Plans 44-59, Plan 47 was selected as the optimum test plan in regard to wave protection, navigation, harbor circulation, and cost of construction. Plan 47, therefore, was subjected to additional testing.

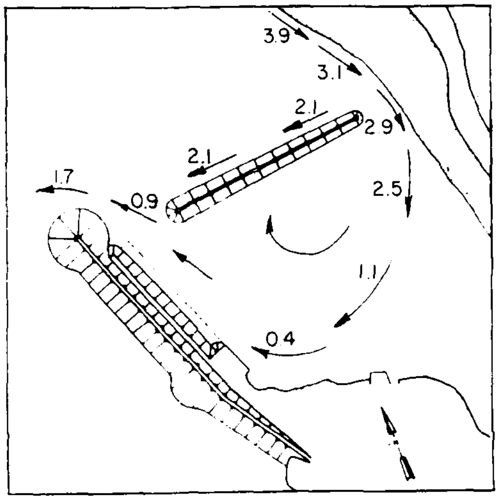
56. Wave heights secured for Plan 47 are presented in Table 17 for test

waves from all five directions. Maximum wave heights were 4.1 ft along the proposed dock (Gage 9) for 16-sec, 19-ft test waves from west-northwest; 2.6 ft in the proposed mooring area (Gages 1 and 12) for 16-sec, 16- and 19-ft test waves from west-northwest; and 4.1 ft at the existing boat ramp (Gage 2) for 12-sec, 19-ft test waves from west. Typical wave patterns for Plan 47 are shown in Photos 82-89.

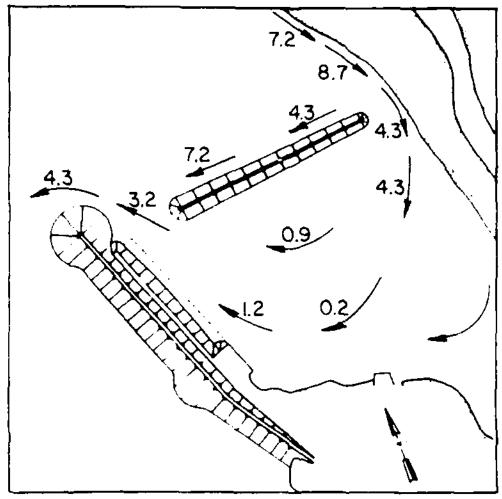
57. The general movement of tracer material and subsequent deposits for representative test waves with Plan 47 installed are shown in Photos 90-93. Sediment patterns were similar for each test series from the various directions. Sediment along the shoreline northeast of the harbor entrance moved in a southerly direction. Some of the material moved westerly along the secondary breakwater, and some penetrated the opening between the shoreline and the shoreward end of the secondary breakwater. Tracer material that entered the harbor through the opening in the shoreline deposited in the lee of the secondary breakwater but did not enter the mooring area. Sediment moving westerly along the outside of the secondary breakwater generally deposited north of the structure and did not enter the entrance channel. Large waves from west-northwest, however, resulted in sediment moving around and seaward of the head of the outer breakwater.

58. Wave-induced current patterns and magnitudes obtained for Plan 47 for representative test waves and directions are shown in Figures 14-17. Maximum velocities obtained at various locations were as follows:

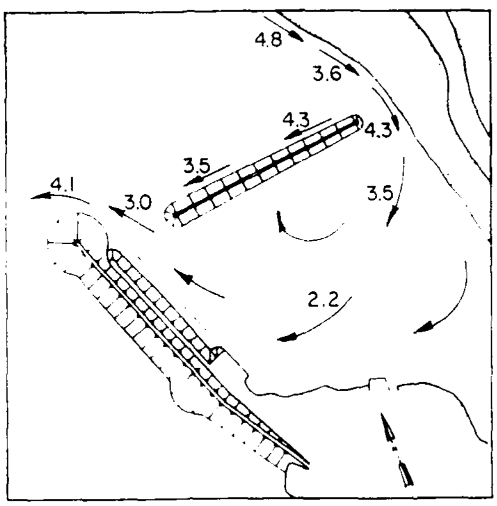
Location	Maximum Velocity, fps	Test Wave(s) Period sec	Test Wave(s) Height ft	Direction(s)
Shoreline along bolder spit northwest of secondary breakwater	8.7	10	13	West-northwest
		12	16	West
		10	25	West-southwest
Opening between shoreward end of secondary breakwater and shoreline	7.9	12	16	West
		16	19	West
		12	19	West-southwest
Area of harbor in lee of secondary breakwater	7.2	16	19	West
Harbor entrance	3.2	10	13	West-northwest
		10	19	South-southwest
Area along head of breakwater extension	4.8	10	19	West
		16	19	West



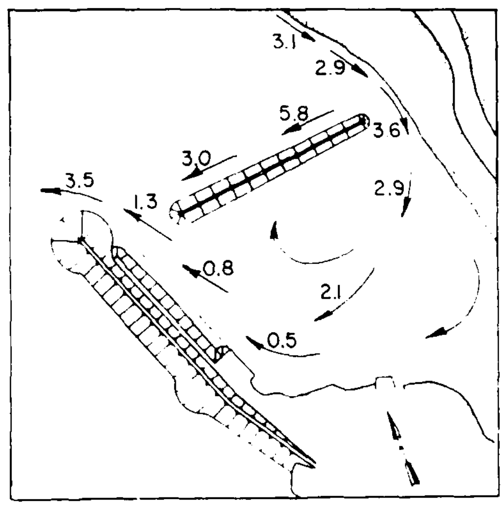
a. 8-sec, 7-ft test waves



b. 10-sec, 13-ft test waves

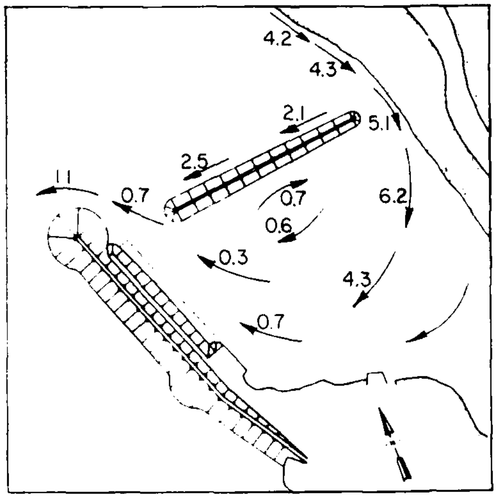


c. 14-sec, 16-ft test waves

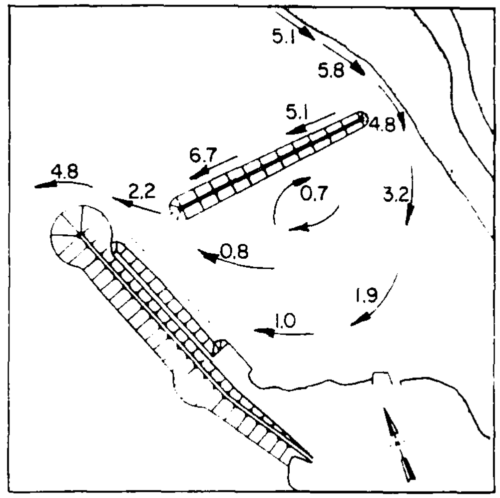


d. 16-sec, 19-ft test waves

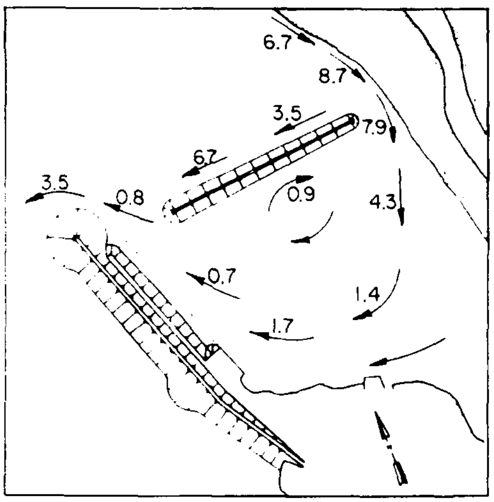
Figure 14. Typical current patterns and magnitudes (prototype feet per second) for Plan 47 for test waves from west-northwest; swl = +3.2 ft



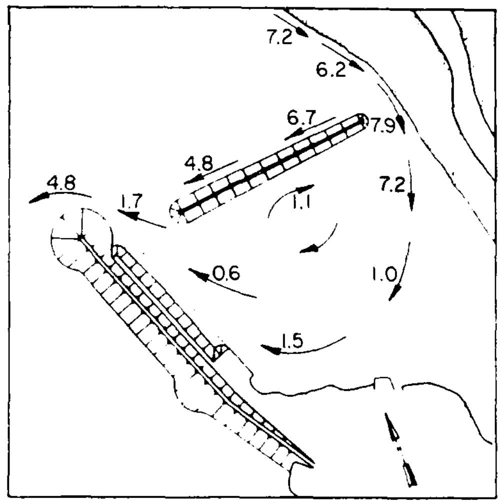
a. 6-sec, 10-ft test waves



b. 10-sec, 19-ft test waves

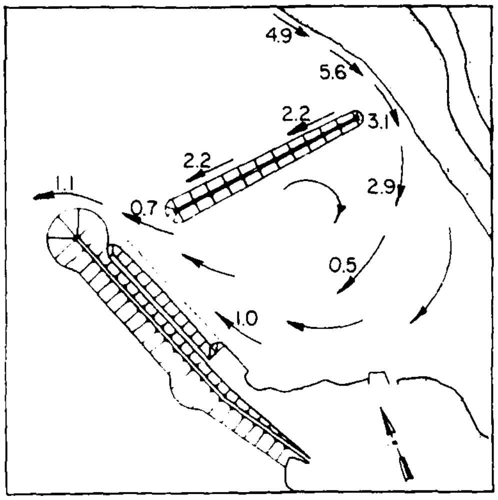


c. 12-sec, 16-ft test waves

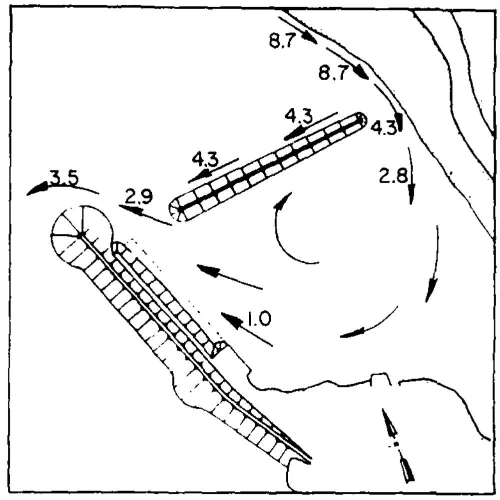


d. 16-sec, 19-ft test waves

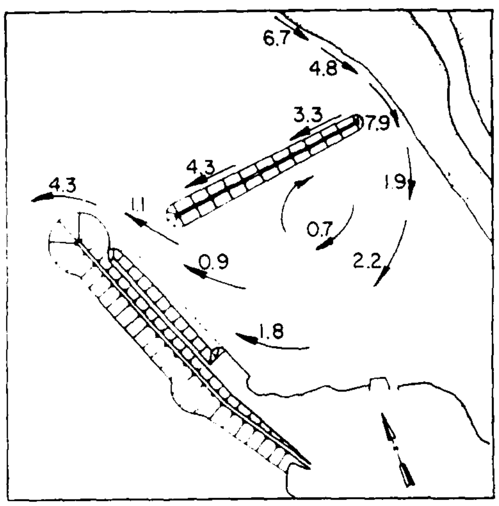
Figure 15. Typical current patterns and magnitudes (prototype feet per second) for Plan 47 for test waves from west; swl = +3.2 ft



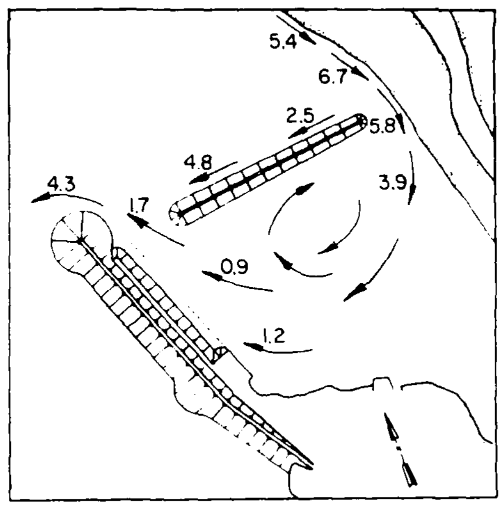
a. 6-sec, 10-ft test waves



b. 10-sec, 25-ft test waves

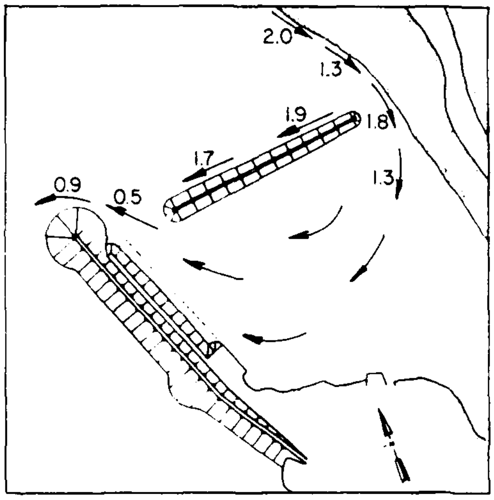


c. 12-sec, 19-ft test waves

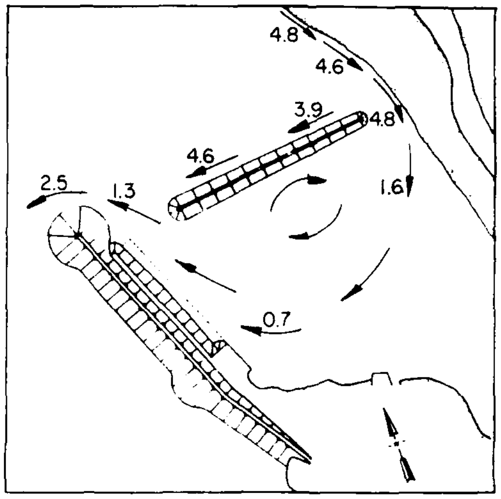


d. 16-sec, 19-ft test waves

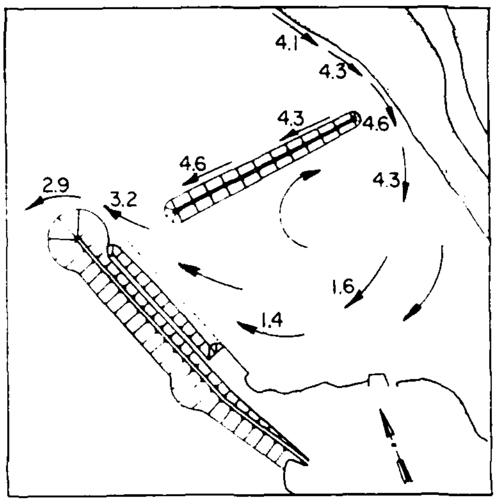
Figure 16. Typical current patterns and magnitudes (prototype feet per second) for Plan 47 for test waves from west-southwest; swl = +3.2 ft



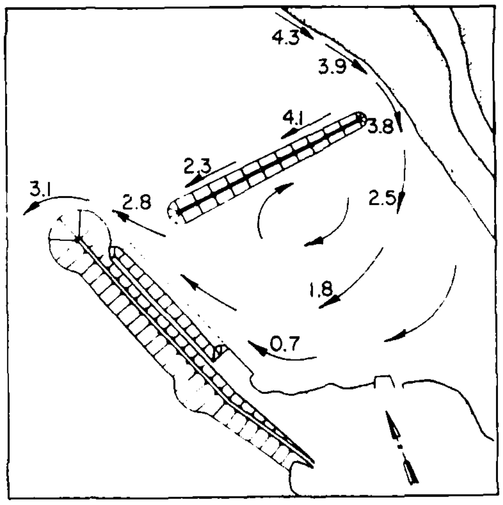
a. 6-sec, 7-ft test waves



b. 8-sec, 13-ft test waves



c. 10-sec, 19-ft test waves



d. 16-sec, 16-ft test waves

Figure 17. Typical current patterns and magnitudes (prototype feet per second) for Plan 47 for test waves from south-southwest; swl = +3.2 ft

In general, currents in the cove moved southerly along the bolder spit to the shoreward end of the secondary breakwater where they split. Currents moved westerly along the seaward side of the secondary breakwater, across the entrance, and offshore adjacent to the head of the main breakwater extension for all test waves and all directions. Currents also moved into the harbor through the opening between the shoreward end of the secondary breakwater and the shoreline. Once inside the harbor, currents in the lee of the secondary breakwater moved in a clockwise direction and exited through the main harbor entrance.

Discussion of test results

59. Wave heights obtained for existing conditions indicated very rough and turbulent wave conditions in the cove and along the existing vertical-walled dock for storm waves from all directions. Storm waves from west-northwest and west resulted in wave heights in excess of 10 ft at the dock. Even less severe, everyday waves with incident heights ranging from 7 to 10 ft resulted in wave heights along the dock that ranged from 3.3 to 7.7 ft from these directions.

60. Results of wave height tests for the initial improvement plan which included the 1,000-ft-long vertical-walled dock (Plan 1) revealed excessive wave heights (6.8 ft) along the proposed dock. The installation of spurs and/or a secondary breakwater (Plans 2-7) resulted in wave heights in excess of the established 2.5-ft wave height criterion at the dock. Wave heights at the dock were 3.5 ft for the best plan tested (Plan 7).

61. Results of wave height tests with the 750-ft-long vertical-walled dock installed (Plans 9-43) indicated that several of the proposed improvement plans would meet the established wave height criterion (Plan 21, 24, 35, 37, 39, and 43). The orientation of the entrance, however, was unacceptable to local interests since the spur and narrow entrance channel would interfere with the passage of 250- to 350-ft long vessels. Tests conducted to this point indicated that the 2.5-ft wave height criterion along the dock could not be achieved without the breakwater spur unless additional structures (i.e. an offshore structure overlapping the breakwater extension) were installed. Based on economics, these structures were not feasible and, consequently, not tested in the model.

62. At this point in the investigation, it was determined that a pile-supported dock (as opposed to a vertical wall dock) would be used in the

study. In addition, it was determined that the 2.5-ft wave height criterion at the dock could be relaxed for the most severe wave conditions provided that vessels could move to an area in the harbor where waves would not exceed 2.5 ft. Results of wave-height tests with the mooring area in the lee of the secondary breakwater (Plans 44-59) revealed that several plans would meet the established criterion. After consideration of wave protection, ease of navigation, wave-induced harbor circulation, and costs, Plan 47 was selected as the optimum improvement plan. Comprehensive wave height tests for Plan 47 indicated that the wave height criterion would be exceeded by 0.1 ft only for the most severe incident wave conditions (16-sec, 16- and 19-ft waves from west-northwest).

63. Results of sediment tracer patterns for Plan 47 indicated that shoaling would not occur in the harbor entrance. Some material moved into the harbor through the opening between the secondary breakwater, and the shoreline but did not settle in the proposed mooring area. The installation of the Plan 47 breakwater structures should have no adverse impact on the movement of sediment in the area.

64. Wave-induced current patterns and velocities obtained for Plan 47 indicated that harbor circulation would occur as a result of the opening between the secondary breakwater and the shoreline. In general, currents move into the harbor in this opening and out through the navigable harbor entrance. Magnitudes in excess of 7 fps in the harbor occur for some of the most severe incident storm wave conditions.

PART V: CONCLUSIONS

65. Based on the results of the hydraulic model investigation reported herein, it was concluded that:

a. Existing conditions are characterized by very rough and turbulent wave conditions (wave heights in excess of 10 ft) along the vertical-walled dock during periods of storm wave attack.

b. The originally proposed breakwater extension with the 1,000-ft-long vertical walled dock (Plan 1) resulted in excessive wave heights (6.8 ft) along the proposed dock. Modifications to this plan, which consisted of the installation of spurs and/or a secondary breakwater, resulted in wave heights in excess of the established wave height criterion of 2.5 ft at the dock.

c. Of the improvement plans tested with the 750-ft-long vertical-walled dock (Plans 9-43), several met the established 2.5-ft wave height criterion at the dock. These improvement plans were not optimal, however, regarding navigation through the proposed entrance configurations.

d. Of the improvement plans tested considering a pile-supported dock system (Plans 44-59), several met the 2.5-ft wave height criterion in the new mooring area situated in the lee of the secondary breakwater.

e. Of all the improvement plans tested (Plans 1-59), Plan 47 was determined optimum considering wave protection, navigation, harbor circulation, and costs. The 2.5-ft wave height criterion will be exceeded by 0.1 ft only for the most severe incident storm wave conditions from west-northwest.

f. The Plan 47 breakwater configuration will have no adverse impact on the movement of sediment in the area, nor will shoaling occur in the harbor entrance or mooring areas.

g. The 200-ft opening between the secondary breakwater of Plan 47 and the shoreline will provide for increased wave-induced harbor circulation.

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Table 1

Summary of Refraction and Shoaling Analysis

for St. Paul Harbor, Alaska

Deep-Water Direction deg	Wave Period sec	Shallow-Water* Azimuth deg	Refraction* Coefficient	Shoaling** Coefficient	Wave-Height Adjustment Factor
West-northwest (292.5)	6	283.3	0.566	0.965	0.546
	8	275.8	0.569	0.918	0.522
	10	270.6	0.628	0.918	0.577
	12	264.7	0.527	0.944	0.497
	14	262.2	0.574	0.982	0.564
	16	259.4	0.657	1.024	0.673
West (270)	6	268.0	0.954	0.965	0.921
	8	263.9	0.865	0.918	0.794
	10	260.2	0.858	0.918	0.788
	12	256.9	0.892	0.944	0.842
	14	254.0	0.913	0.982	0.897
	16	251.4	0.889	1.024	0.910
West-southwest (247.5)	6	247.6	0.998	0.965	0.963
	8	246.7	1.003	0.918	0.921
	10	245.0	0.966	0.918	0.887
	12	244.0	0.914	0.944	0.863
	14	242.9	0.882	0.982	0.866
	16	242.0	0.855	1.024	0.876
Southwest (225)	6	227.8	0.803	0.965	0.775
	8	231.2	0.723	0.918	0.664
	10	233.5	0.648	0.918	0.595
	12	234.0	0.613	0.944	0.579
	14	235.0	0.591	0.982	0.580
	16	235.8	0.583	1.024	0.597
South-southwest (202.5)	6	224.9	0.554	0.965	0.535
	8	229.7	0.783	0.918	0.719
	10	233.4	0.754	0.918	0.692
	12	233.7	0.442	0.944	0.417
	14	231.7	0.556	0.982	0.546
	16	235.1	0.498	1.024	0.510

* At approximate locations of wave generator in model.

** At 65-ft depth (60-ft pit elevation with 5-ft storm conditions superimposed).

Table 2

Estimated Magnitude of Deepwater Waves (Sea and Swell) Approaching St. Paul Harbor from the Directions Indicated

Wave Height ft	Occurrences* per Wave Period, sec							
	4.4-6.0	6.1-8.0	8.1-10.5	10.6-13.3	13.4-15.3	15.4-18.1	>18.2	Total
				West-northwest				
0.0-3.3	3	--	1	--	--	--	--	4
3.3-6.6	18	41	108	1	--	--	--	168
6.6-9.8	7	36	137	40	1	--	--	221
9.8-13.1	--	23	41	74	1	--	--	139
13.1-16.4	--	--	20	61	5	--	--	86
16.4-19.7	--	--	8	31	7	1	--	47
19.7-23.0	--	--	1	3	8	--	--	12
23.0-26.2	--	--	--	--	4	1	--	5
26.2-29.5	--	--	--	--	--	--	--	--
29.5-32.8	--	--	--	--	--	1	--	1
>32.8	--	--	--	--	--	1	--	1
Total	28	100	316	210	26	4	--	684
				West				
0.0-3.3	2	05	10	--	--	--	--	17
3.3-6.6	19	64	124	3	--	--	--	210
6.6-9.8	18	65	220	46	--	--	--	349
9.8-13.1	1	50	101	142	3	--	--	297
13.1-16.4	--	1	51	161	12	--	--	225
16.4-19.7	--	--	29	54	16	1	--	100
19.7-23.0	--	--	2	28	14	--	--	44
23.0-26.2	--	--	--	13	8	--	--	21
26.2-29.5	--	--	--	5	4	1	--	10
29.5-32.8	--	--	--	1	3	--	--	4
>32.8	--	--	--	1	2	1	--	4
Total	40	185	537	454	62	3	--	1,281
				West-southwest				
0.0-3.3	1	2	4	--	--	--	--	7
3.3-6.6	9	50	65	3	--	--	--	127
6.6-9.8	16	81	159	31	1	--	--	288
9.8-13.1	--	48	76	87	--	--	--	211
13.1-16.4	--	3	55	134	4	--	--	196
16.4-19.7	--	--	24	64	23	1	--	112
19.7-23.0	--	--	4	35	20	--	--	59
23.0-26.2	--	--	1	17	10	2	--	30
26.2-29.5	--	--	--	7	4	--	--	11
29.5-32.8	--	--	--	2	1	--	--	3
>32.8	--	--	--	1	--	2	--	3
Total	26	184	388	381	63	5	--	1,047

(Continued)

* Occurrences compiled for period 1966-1975. Each occurrence represents a 6-hr duration.

Table 2 (Concluded)

Wave Height ft	Occurrences per Wave Period, sec							
	4.4-6.0	6.1-8.0	8.1-10.5	10.6-13.3	13.4-15.3	15.4-18.1	>18.2	Total
				Southwest				
0.0-3.3	1	4	1	--	--	--	--	6
3.3-6.6	7	33	51	--	--	--	--	91
6.6-9.8	10	43	121	23	--	--	--	197
9.8-13.1	--	24	66	72	1	--	--	163
13.1-16.4	--	1	50	102	2	--	--	155
16.4-19.7	--	--	19	70	17	--	--	106
19.7-23.0	--	--	5	44	19	--	--	68
23.0-26.2	--	--	1	31	17	1	--	50
26.2-29.5	--	--	--	15	6	2	--	23
29.5-32.8	--	--	--	6	3	1	--	10
>32.8	--	--	--	--	3	--	--	3
Total	18	105	314	363	68	4	--	872
				South-southwest				
0.0-3.3	--	3	--	--	--	--	--	3
3.3-6.6	5	22	58	2	--	--	--	87
6.6-9.8	2	36	106	10	--	--	--	154
9.8-13.1	--	13	52	60	--	--	--	125
13.1-16.4	--	2	25	107	4	--	--	138
16.4-19.7	--	--	25	57	10	--	--	92
19.7-23.0	--	--	11	31	14	--	--	56
23.0-26.2	--	--	1	17	10	--	--	28
26.2-29.5	--	--	--	8	5	2	--	15
29.5-32.8	--	--	--	4	5	--	--	9
>32.8	--	--	--	1	12	--	--	13
Total	7	76	278	297	60	2	--	720

Table 3

Estimated Magnitude of Shallow-Water Waves (Sea and Swell) Approaching St. Paul Harbor from the Directions Indicated

Wave Height ft	Occurrences* per Wave Period, sec 4.4-6.0	6.1-8.0	8.1-10.5	10.6-13.3	13.4-15.3	15.4-18.1	>18.2	Total
				West-northwest				
0-4	21	41	109	1	--	--	--	172
4-7	7	59	137	114	1	--	--	318
7-10	--	--	61	92	6	--	--	159
10-13	--	--	9	3	15	--	--	27
13-16	--	--	--	--	4	1	--	5
16-19	--	--	--	--	--	1	--	1
19-22	--	--	--	--	--	1	--	1
>22	--	--	--	--	--	1	--	1
Total	28	100	316	210	26	4	--	684
				West				
0-4	2	5	10	--	--	--	--	17
4-7	19	64	124	3	--	--	--	210
7-10	18	65	220	46	--	--	--	349
10-13	1	51	152	142	3	--	--	349
13-16	--	--	29	161	12	--	--	202
16-19	--	--	2	82	16	1	--	101
19-22	--	--	--	13	14	--	--	27
22-25	--	--	--	5	8	--	--	13
25-28	--	--	--	1	4	1	--	6
28-31	--	--	--	1	3	1	--	5
>31	--	--	--	--	2	--	--	2
Total	40	185	537	454	62	3	--	1,281
				West-southwest				
0-4	1	2	4	--	--	--	--	7
4-7	9	50	65	3	--	--	--	127
7-10	16	81	159	31	1	--	--	288
10-13	--	48	76	87	--	--	--	211
13-16	--	3	55	134	4	--	--	196
16-19	--	--	24	64	23	1	--	112
19-22	--	--	4	35	20	--	--	59
22-25	--	--	1	17	10	2	--	30
25-28	--	--	--	9	5	--	--	14
>28	--	--	--	1	--	2	--	3
Total	26	184	388	381	63	5	--	1,047

(Continued)

* Occurrences compiled for period 1966-1975. Each occurrence represents a 6-hr duration.

Table 3 (Concluded)

Wave Height ft	Occurrences per Wave Period, sec 4.4-6.0	6.1-8.0	8.1-10.5	10.6-13.3	13.4-15.3	15.4-18.1	>18.2	Total
				Southwest				
0-4	1	4	52	--	--	--	--	57
4-7	7	76	121	23	--	--	--	227
7-10	10	24	116	174	3	--	--	327
10-13	--	1	19	70	17	--	--	107
13-16	--	--	6	75	36	1	--	118
16-19	--	--	--	21	9	2	--	32
>19	--	--	--	--	3	1	--	4
Total	18	105	314	363	68	4	--	872
				South-southwest				
0-4	5	3	--	12	--	--	--	20
4-7	2	58	164	167	--	--	--	391
7-10	--	13	52	88	4	--	--	157
10-13	--	2	25	25	24	--	--	76
13-16	--	--	36	5	15	2	--	58
16-19	--	--	1	--	5	--	--	6
>19	--	--	--	--	12	--	--	12
Total	7	76	278	297	60	2	--	720

Table 4

Wave Heights for Existing Conditions

swl = +5.0 ft

	Test Wave		Wave Height, ft								
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9
West-northwest	6	7	1.3	3.3	2.9	3.3	7.6	8.4	7.6	7.4	7.8
	8	7	1.9	3.2	3.3	4.4	7.2	8.3	7.0	7.1	9.2
	10	7	2.4	3.4	3.6	5.3	6.6	7.6	6.7	6.8	8.9
	--	13	4.9	7.0	5.8	7.0	12.5	15.4	13.5	14.7	14.3
	12	7	3.1	4.2	4.3	6.7	7.6	8.9	8.9	8.6	8.6
	--	13	6.4	7.6	6.8	8.3	13.2	17.4	17.4	16.5	15.8
	14	10	5.1	5.4	5.8	7.7	9.1	12.9	12.5	11.8	12.6
	--	16	8.0	6.8	6.6	8.4	15.1	15.8	18.4	15.2	15.5
	16	16	9.9	8.1	7.9	9.5	16.3	16.0	18.3	16.4	15.9
	--	19	10.1	8.1	7.7	10.1	15.2	15.9	19.3	15.8	16.8
West	6	10	1.9	3.4	3.1	4.1	9.3	9.5	8.6	8.8	10.2
	8	10	2.7	3.8	3.4	5.1	9.1	9.6	9.9	9.8	11.6
	10	10	3.7	5.0	4.4	6.5	9.4	10.2	10.3	10.0	12.5
	--	19	6.9	7.4	6.1	7.5	11.3	15.4	16.0	16.9	15.5
	12	16	7.3	7.1	6.5	8.4	10.5	16.5	16.9	15.5	15.4
	--	19	8.1	7.7	6.9	9.1	13.0	16.6	19.8	15.0	17.0
	14	16	8.0	6.7	6.7	9.9	11.9	18.3	16.6	16.8	15.4
	16	19	10.2	7.8	7.4	10.1	14.1	17.6	19.5	17.2	16.0
West-southwest	6	10	1.9	3.6	2.6	4.7	9.3	8.9	9.3	9.3	10.0
	8	10	2.7	4.5	3.6	5.2	10.6	11.1	11.6	10.8	11.0
	--	16	4.2	5.1	4.6	6.1	12.8	15.0	15.8	15.0	15.3
	10	10	3.6	5.6	4.5	6.0	9.9	12.6	13.6	12.1	12.6
	--	25	8.4	8.7	7.7	10.0	15.4	17.6	18.5	18.5	19.8
	12	16	7.4	7.5	7.1	9.2	13.5	17.5	18.4	17.7	19.8
	--	19	8.1	7.1	6.8	9.8	13.1	18.4	17.9	18.6	21.6
	14	16	8.0	6.8	6.8	9.6	14.1	17.3	19.3	17.5	18.6
	16	19	10.2	6.7	7.5	9.7	14.1	17.6	17.9	18.1	21.3
Southwest	6	10	1.9	2.2	1.9	2.8	7.2	9.2	9.8	9.6	9.7
	8	7	1.9	2.3	1.9	3.4	6.1	9.1	8.4	8.7	8.2
	--	13	3.9	4.5	3.4	4.9	9.3	14.2	13.9	14.6	14.0
	10	7	2.4	3.1	2.4	4.0	5.2	9.2	8.8	8.7	8.2
	--	16	5.4	5.8	5.0	7.1	11.4	15.6	17.7	16.4	17.9
	12	10	5.3	6.5	4.8	7.0	9.6	14.8	15.2	14.6	16.1
	--	19	8.1	6.7	6.0	8.2	11.7	17.4	19.8	17.6	18.7
	14	16	8.0	6.7	5.6	7.9	12.1	16.7	18.0	17.5	18.4
	16	19	10.2	6.6	6.3	8.2	12.2	17.0	18.6	18.0	18.8
South-southwest	6	7	1.3	1.8	1.4	2.2	5.1	7.6	8.5	8.4	8.3
	8	7	1.9	2.1	1.6	2.4	4.5	5.5	8.0	8.9	8.4
	--	13	3.7	4.5	3.9	4.8	8.8	13.6	13.1	14.2	13.9
	10	7	2.4	2.9	2.0	3.2	4.7	8.2	8.2	8.4	8.1
	--	19	6.8	6.4	4.9	7.1	11.1	16.3	18.7	16.6	17.0
	12	7	3.1	3.7	2.4	4.0	5.3	8.6	8.7	8.6	8.1
	--	16	7.4	7.0	5.2	7.5	10.7	17.1	18.7	17.4	17.1
	14	10	5.1	5.1	4.2	6.2	7.1	10.2	10.6	11.2	12.1
	--	16	8.0	6.8	5.2	7.8	10.4	15.4	16.3	17.7	17.8
	16	16	10.0	6.5	5.9	8.2	10.6	14.6	16.7	17.2	18.4

Table 5

Wave Heights for Plan 1

swl = +5.0 ft

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13
West-northwest	6	7	1.5	1.6	1.0	1.3	1.1	1.5	1.2	1.2	1.4	3.0	1.8	2.4	2.8
	8	7	2.0	1.8	1.4	1.8	1.5	1.6	1.6	1.6	1.9	3.1	2.1	2.8	3.2
	10	7	2.3	2.4	1.9	2.2	1.6	1.8	1.9	1.8	2.1	3.1	2.5	2.6	3.0
	--	13	4.5	5.5	3.7	4.3	3.0	3.1	3.6	3.6	3.8	5.1	3.7	4.2	6.4
	12	7	3.2	3.8	2.2	2.7	2.0	2.2	2.5	2.7	2.7	3.9	3.0	3.6	4.3
	--	13	5.5	6.7	4.7	5.8	3.8	4.1	5.0	5.0	4.8	6.3	4.4	4.8	8.3
	14	10	5.1	5.2	3.8	4.6	3.2	3.4	3.6	3.6	3.8	5.4	4.1	4.6	5.6
	--	16	5.9	6.8	5.2	6.2	4.2	4.4	5.0	4.9	5.5	6.4	5.3	5.0	8.5
	16	16	6.5	7.6	5.6	6.8	4.6	5.1	5.9	6.3	6.4	7.1	5.7	5.6	9.2
	--	19	6.5	6.8	5.4	6.6	4.8	5.2	5.9	6.4	6.4	7.2	5.8	5.7	8.5
West	6	10	2.0	2.1	1.6	1.9	1.4	1.4	1.6	1.4	1.7	2.5	1.8	2.4	2.5
	8	10	2.6	3.2	2.2	2.4	2.2	1.9	2.1	2.1	2.2	3.4	2.5	3.4	3.2
	10	10	3.7	5.4	3.1	3.4	2.6	2.6	2.7	2.6	2.9	4.1	3.1	4.0	3.9
	--	19	5.0	7.5	4.4	5.1	3.3	3.2	4.2	4.1	4.6	5.3	4.1	4.8	6.4
	12	16	5.5	6.7	5.1	5.9	3.9	3.7	4.9	4.5	4.8	5.5	4.2	5.4	6.8
	--	19	6.1	7.2	5.1	5.6	3.7	4.1	4.5	4.5	5.2	5.8	4.4	5.5	7.4
	14	16	6.1	7.0	5.0	5.2	3.8	4.0	4.9	4.7	5.4	5.6	4.6	5.0	6.2
	16	19	6.1	7.2	4.7	5.8	4.0	4.2	4.8	4.7	5.5	5.7	4.5	5.0	7.4
West-southwest	6	10	1.6	1.8	1.9	2.4	1.3	1.6	2.4	2.0	1.8	2.2	1.7	1.8	1.7
	8	10	2.4	3.3	2.6	3.0	2.3	2.1	2.9	2.9	2.3	2.8	2.2	2.4	2.1
	--	16	3.2	4.3	3.3	4.1	3.0	2.9	3.9	4.0	3.2	3.5	2.9	3.5	3.8
	10	10	3.0	4.4	3.4	4.4	2.8	2.5	3.6	3.6	3.1	3.1	2.8	3.3	2.3
	--	25	5.9	7.0	6.0	6.8	4.7	5.0	6.4	6.6	6.2	6.0	4.9	6.4	7.0
	12	16	5.1	6.4	4.8	6.1	4.5	4.2	5.7	6.1	5.5	5.4	4.5	5.5	6.5
	--	19	5.3	6.4	4.9	5.8	4.4	4.4	5.9	6.1	5.6	6.1	4.9	6.0	6.6
	14	16	5.5	6.4	5.1	6.4	4.8	4.5	5.5	6.2	5.9	5.5	4.6	5.5	5.4
	16	19	5.0	6.5	5.3	6.1	4.3	4.4	5.3	5.8	5.6	5.8	4.8	5.7	5.7

Table 6

Wave Heights for Plans 2-4 for Test Waves from West-Northwest

swl = +5.0 ft

Test Wave		Wave Height, ft												
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13
							Plan 2							
6	7	1.3	1.3	0.8	1.1	0.8	1.4	1.1	1.0	0.4	3.2	1.2	1.1	1.2
10	13	4.1	5.1	3.2	3.6	2.6	2.4	2.9	2.7	1.6	5.3	3.0	3.0	4.4
12	13	4.8	5.9	3.7	5.0	3.1	3.1	4.0	3.1	2.3	5.7	3.7	3.5	5.6
14	16	5.1	6.2	4.1	5.6	3.4	3.5	4.3	3.6	2.7	6.2	4.0	4.3	6.7
16	16	6.0	7.3	4.2	5.8	3.5	3.7	4.7	3.7	2.8	6.9	4.6	4.5	7.4
--	19	5.8	6.8	5.0	6.0	4.1	4.0	4.8	4.0	3.1	7.2	5.1	5.1	7.4
							Plan 3							
6	7	1.7	1.3	0.8	1.0	0.9	0.9	0.8	0.7	0.4	3.2	1.3	1.1	1.2
10	13	4.0	5.5	3.1	3.3	2.5	1.9	2.5	2.1	1.6	5.6	3.6	3.5	4.3
12	13	4.7	5.4	3.4	4.3	2.7	2.2	3.1	2.4	2.0	5.9	3.7	4.0	5.2
14	16	5.5	6.1	4.1	4.7	3.2	2.5	3.9	3.0	2.0	6.4	4.1	5.0	6.8
16	16	6.2	6.8	4.0	5.0	3.2	2.8	4.1	3.1	2.7	7.3	4.6	5.2	7.7
--	19	6.5	6.9	4.1	5.4	3.3	2.9	4.2	3.5	2.9	6.9	4.8	5.3	7.0
							Plan 4							
6	7	1.7	1.4	0.8	0.8	0.8	0.7	0.7	0.7	0.5	3.5	1.2	1.1	1.1
10	13	4.1	5.1	3.3	3.6	2.4	1.7	2.6	2.2	1.6	5.8	3.2	3.6	4.3
12	13	5.1	5.7	3.6	4.0	2.7	2.0	3.0	2.3	2.3	6.0	3.7	4.1	5.5
14	16	5.3	6.0	3.7	4.9	2.8	2.1	3.3	2.8	2.1	6.4	4.0	4.7	6.5
16	16	6.3	6.5	3.7	4.9	3.0	2.4	3.6	3.0	2.7	7.4	4.3	5.1	7.0
--	19	6.5	7.0	3.8	5.3	3.3	2.7	4.0	3.4	3.1	7.4	4.7	5.5	7.6

Table 7

Wave Heights for Plans 5-8 for Test Waves from West-Northwest

swl = +5.0 ft

Test Wave		Wave Height, ft												
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13
						Plan 5								
6	7	0.6	0.9	0.6	1.1	0.8	1.4	1.1	1.1	1.4	1.7	0.7	0.7	0.8
10	13	1.9	2.8	1.8	2.4	1.9	2.6	2.5	2.8	3.4	3.3	1.8	1.8	2.3
12	13	2.4	3.1	2.6	3.3	2.5	3.4	3.3	3.4	3.9	4.2	2.2	2.3	2.7
14	16	2.6	3.5	2.5	3.3	2.7	3.4	3.3	3.5	4.2	4.3	2.4	2.4	2.9
16	16	2.7	3.7	2.5	3.4	2.5	3.7	3.3	3.7	4.3	4.7	2.6	2.6	3.0
--	19	2.7	3.9	2.7	3.6	2.8	4.0	3.6	4.1	4.6	5.0	2.6	2.8	3.4
						Plan 6								
6	7	0.6	0.7	0.5	1.2	0.6	1.2	1.1	1.0	0.6	1.6	0.7	0.7	0.7
10	13	2.0	2.4	1.8	2.2	1.7	2.3	2.2	2.3	1.8	3.4	1.9	1.9	2.1
12	13	2.6	3.5	2.3	3.3	2.4	2.9	3.0	2.9	2.4	4.7	2.6	2.9	2.6
14	16	2.8	3.7	2.6	3.5	2.6	3.1	3.2	3.2	2.9	5.2	2.8	2.6	3.0
16	16	3.2	3.9	2.7	3.6	2.4	3.3	3.2	3.6	3.0	5.3	3.1	2.8	3.2
--	19	2.9	3.9	2.6	3.6	2.5	3.3	3.4	3.5	3.0	5.4	2.9	2.8	3.2
						Plan 7								
6	7	0.7	0.7	0.5	0.8	0.6	0.7	0.7	0.6	0.5	1.5	0.9	0.6	0.6
10	13	2.0	2.9	1.6	2.1	1.6	1.7	1.9	1.8	1.5	3.7	1.9	1.9	2.0
12	13	2.7	3.3	2.2	2.7	2.0	2.3	2.5	2.2	1.9	4.8	2.7	2.4	2.7
14	16	3.0	3.8	2.4	3.1	2.3	2.5	2.7	2.7	2.4	5.7	3.0	2.5	3.0
16	16	3.1	3.7	2.4	3.4	2.4	2.4	2.8	2.7	2.6	5.6	3.0	2.7	3.1
--	19	3.1	3.8	2.4	3.5	2.2	2.6	3.0	3.0	2.5	5.7	3.1	2.8	3.0
						Plan 8								
6	7	0.4	0.6	0.4	0.5	0.4	0.5	0.5	0.4	0.4	3.4	0.4	0.4	0.4
10	13	1.5	2.3	1.2	1.4	1.0	1.2	1.3	1.3	1.4	6.1	1.3	1.2	1.6
12	13	2.1	2.9	1.7	2.0	1.3	1.6	1.7	1.6	1.7	7.0	1.8	1.6	2.1
14	16	2.3	2.8	1.6	2.1	1.5	1.7	1.9	1.9	1.9	6.9	2.1	2.0	2.3
16	16	2.6	3.4	1.6	2.3	1.5	1.8	1.9	2.0	2.0	8.1	2.1	2.1	2.5
--	19	2.4	3.1	1.7	2.4	1.6	1.8	2.0	2.0	1.9	7.6	2.1	2.1	2.4

Table 8

Wave Heights for Plans 9-12 for Test Waves from West-Northwest

swl = +5.0 ft

Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 10	Gage 11	Gage 12	Gage 13
						Plan 9							
12	13	5.4	6.0	4.3	5.0	3.1	3.3	4.2	3.4	3.7	4.0	4.5	5.6
14	16	5.9	6.6	4.4	6.1	3.5	3.5	4.2	3.6	4.0	4.4	4.8	6.4
16	16	6.2	6.7	4.3	5.8	3.6	3.6	4.4	3.6	4.7	5.0	5.5	6.8
--	19	7.0	7.2	4.7	6.2	4.2	4.2	5.1	4.1	5.2	5.2	5.7	6.8
						Plan 10							
12	13	5.0	6.0	3.7	5.0	2.9	2.6	3.7	2.6	3.5	3.6	4.4	5.6
14	16	5.9	5.9	4.1	5.5	3.0	2.8	3.5	2.8	3.9	4.2	4.7	6.3
16	16	6.6	6.8	4.0	5.6	3.2	3.0	3.8	3.0	4.4	4.4	4.7	6.1
--	19	6.8	6.3	3.9	5.4	3.3	3.0	3.8	3.0	4.2	4.3	4.9	6.1
						Plan 11							
12	13	5.0	5.5	3.5	4.6	2.6	2.0	3.1	2.4	3.5	3.3	4.0	5.4
14	16	5.5	5.7	3.8	5.0	2.8	2.0	3.4	2.5	4.1	4.1	4.4	6.2
16	16	6.5	6.1	3.8	4.9	2.9	2.1	3.5	2.7	4.4	4.0	4.7	6.2
--	19	6.6	6.6	3.8	4.5	2.9	2.1	3.3	2.6	4.7	4.1	4.8	5.8
						Plan 12							
12	13	5.4	5.7	3.4	4.4	2.4	1.8	2.9	2.2	3.9	2.9	3.8	5.1
14	16	5.3	5.4	3.9	4.7	2.6	1.9	3.2	2.1	4.4	3.4	4.[illegible]	5.8
16	16	6.1	6.1	4.1	5.0	2.7	2.1	3.2	2.5	4.7	3.5	4.5	6.0
--	19	6.4	6.3	3.6	4.8	2.9	2.1	3.5	2.6	5.1	3.8	4.5	6.0

Table 9

Wave Heights for Plans 13-16 for Test Waves from West-Northwest

swl = +5.0 ft

Test Wave		Wave Height, ft											
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 10	Gage 11	Gage 12	Gage 13
						Plan 13							
12	13	3.7	5.5	3.7	4.1	2.9	3.2	3.8	3.0	4.3	3.0	3.1	4.5
14	16	4.0	5.4	3.8	4.9	3.1	3.6	4.1	3.1	4.9	3.2	3.6	4.8
16	16	4.7	6.0	3.8	4.7	3.3	3.8	4.3	3.2	5.7	4.0	4.1	5.5
--	19	4.5	5.2	4.0	5.1	3.3	4.0	4.5	3.3	5.6	4.1	3.9	5.3
						Plan 14							
12	13	3.6	5.2	3.3	4.0	2.6	3.2	3.4	2.9	4.3	2.6	2.8	4.0
14	16	3.9	4.8	3.3	4.3	2.8	3.3	3.9	3.0	5.0	2.8	3.3	4.4
16	16	4.4	5.5	3.4	4.2	2.9	3.6	3.8	2.9	5.5	3.4	3.5	4.8
--	19	4.3	5.3	3.6	4.9	3.2	4.1	4.5	3.3	5.4	3.4	3.6	4.9
						Plan 15							
12	13	3.7	5.1	3.3	3.6	2.4	2.5	2.9	2.2	4.9	2.8	3.1	4.1
14	16	3.8	4.6	3.0	3.8	2.7	2.5	3.1	2.1	5.2	3.0	3.1	4.4
16	16	4.2	5.5	3.0	3.8	2.8	2.8	3.4	2.2	5.8	3.6	3.5	4.9
--	19	4.4	5.3	2.9	3.9	2.7	2.9	3.4	2.4	5.6	3.4	3.4	4.8
						Plan 16							
12	13	2.6	3.4	1.9	2.4	1.8	2.2	2.3	1.8	4.3	2.8	2.2	2.5
14	16	2.9	3.9	2.1	3.0	2.4	2.5	2.9	2.3	5.0	3.1	2.6	2.7
16	16	3.2	4.0	2.2	3.1	2.2	2.6	2.9	2.1	5.3	3.2	2.7	2.9
--	19	3.4	4.1	2.4	3.1	2.5	2.7	3.0	2.4	5.4	3.4	2.8	3.0

Table 10

Wave Heights for Plans 17-21 for Test Waves from West-Northwest

swl = +5.0 ft

Test Wave		Wave Height, ft											
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 10	Gage 11	Gage 12	Gage 13
						Plan 17							
12	13	2.6	3.6	2.0	2.6	2.0	2.5	2.6	2.3	4.6	3.0	2.5	2.7
14	16	3.4	4.0	2.3	3.1	2.5	2.9	3.0	2.4	5.4	3.4	2.8	2.8
16	16	3.1	4.3	2.3	3.0	2.4	2.9	2.8	2.2	5.6	3.3	2.8	3.0
--	19	3.1	4.0	2.4	3.1	2.4	2.8	2.9	2.5	5.4	3.2	2.8	3.1
						Plan 18							
12	13	2.4	3.4	2.0	2.6	2.2	2.6	2.4	2.0	4.5	2.7	2.3	2.5
14	16	2.8	3.8	2.2	3.0	2.4	2.7	2.9	2.4	5.2	3.1	2.6	2.7
16	16	3.1	3.8	2.4	3.2	2.6	3.2	3.1	2.8	5.5	3.0	2.9	3.0
--	19	3.6	4.4	2.8	3.8	2.8	3.6	3.5	3.1	6.4	3.6	3.1	3.6
						Plan 19							
12	13	2.8	3.5	2.0	2.6	2.0	2.3	2.5	1.9	5.0	2.8	2.4	2.6
14	16	3.1	3.8	2.3	2.8	2.3	2.4	2.6	2.1	5.5	3.2	2.6	2.9
16	16	3.1	4.0	2.4	3.3	2.5	2.8	2.9	2.5	6.2	3.3	2.7	3.0
--	19	3.2	4.0	2.4	3.1	2.5	2.7	2.9	2.5	5.8	3.2	2.8	3.1
						Plan 20							
16	16	2.8	3.4	2.4	3.1	2.4	2.8	2.9	2.2	5.8	3.1	2.6	2.8
--	19	2.9	3.5	2.3	3.1	2.4	2.8	2.9	2.3	5.8	3.1	2.6	3.0
						Plan 21							
12	13	2.7	3.1	1.5	1.9	1.6	1.4	1.7	1.5	4.9	2.5	2.2	2.3
14	16	2.9	3.4	1.6	2.4	1.8	1.6	1.9	1.6	5.1	2.5	2.2	2.4
16	16	3.0	3.5	1.7	2.5	1.9	1.8	2.2	1.7	5.4	2.8	2.4	2.6
--	19	3.1	3.5	1.7	2.5	2.0	1.9	2.2	1.9	5.6	2.7	2.5	2.6

Table 11

Wave Heights for Plans 22-27 for Test Waves from West-Northwest

swl = +5.0 ft

Test Wave		Wave Height, ft											
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 10	Gage 11	Gage 12	Gage 13
						Plan 22							
12	13	2.2	2.8	1.9	2.0	1.6	1.7	1.8	1.6	10.1	1.9	1.7	2.2
14	16	2.8	2.9	2.0	2.3	1.8	2.0	2.3	1.7	11.4	2.5	2.0	2.3
16	16	3.1	3.4	1.9	2.7	1.9	2.4	2.5	1.8	11.4	2.8	2.4	2.6
--	19	3.1	3.4	1.9	2.6	1.9	2.4	2.4	1.9	12.0	2.9	2.4	2.6
						Plan 23							
12	13	3.2	4.4	2.5	2.9	1.8	2.0	2.3	1.8	9.1	2.4	2.5	3.5
14	16	3.1	4.4	2.4	2.9	1.9	2.1	2.5	1.7	11.0	2.7	2.6	3.6
16	16	4.0	5.0	2.8	3.2	2.2	2.6	3.1	1.9	12.1	3.1	3.0	4.2
--	19	3.8	4.8	2.8	3.2	2.2	2.5	2.9	1.9	12.0	3.1	2.9	4.1
						Plan 24							
16	16	2.8	3.3	1.8	2.4	1.7	2.0	2.1	1.7	12.7	2.4	2.4	2.5
--	19	2.9	3.3	1.8	2.4	1.7	2.1	2.1	2.4	12.6	2.4	2.4	2.3
						Plan 25							
16	16	2.6	3.4	2.1	2.7	1.8	2.2	2.4	1.8	12.8	2.7	2.6	2.5
--	19	3.0	3.3	1.8	2.5	1.8	2.1	2.2	1.7	11.8	2.6	2.5	2.4
						Plan 26							
16	16	2.8	3.5	1.9	2.6	1.6	1.8	2.1	1.5	12.4	2.5	2.4	2.4
--	19	2.9	3.4	2.1	2.6	1.6	1.7	2.0	1.6	12.8	2.5	2.5	2.5
						Plan 27							
16	16	3.2	3.5	2.1	2.8	1.7	1.9	2.4	1.6	12.7	2.7	2.7	2.5
--	19	3.0	3.4	2.1	2.7	1.8	1.9	2.4	1.6	12.9	2.7	2.7	2.5

Table 12

Wave Heights for Plans 28-34 for Test Waves from West-Northwest

swl = +5.0 ft

Test Wave		Wave Height, ft											
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 10	Gage 11	Gage 12	Gage 13
						Plan 28							
16	16	2.3	3.5	2.6	3.1	2.4	2.6	2.8	2.2	4.2	2.5	2.5	2.4
--	19	2.3	3.0	2.4	2.9	2.1	2.4	2.6	2.1	4.1	2.4	2.4	2.3
						Plan 29							
16	16	6.1	5.0	2.8	3.7	2.2	2.5	3.0	2.4	4.0	2.6	2.8	3.0
--	19	6.4	5.3	2.7	3.5	2.2	3.0	2.8	2.4	3.7	2.4	2.7	3.1
						Plan 30							
16	16	6.5	5.0	2.4	2.8	2.0	2.2	2.6	2.2	3.9	2.5	2.8	2.9
--	19	6.2	5.0	2.5	3.2	2.4	2.4	3.0	2.5	4.2	2.6	2.7	3.1
						Plan 31							
16	16	6.6	4.7	2.1	2.7	1.9	2.1	2.5	2.1	4.1	1.8	2.5	2.8
--	19	6.4	4.7	2.3	2.6	2.0	2.4	2.5	2.2	4.1	1.9	2.4	2.8
						Plan 32							
16	16	6.5	4.9	2.2	2.7	1.9	2.0	2.4	2.0	3.2	2.2	2.7	3.0
--	19	6.4	4.8	2.3	2.7	2.0	2.0	2.5	2.1	3.4	2.2	2.7	3.0
						Plan 33							
16	16	6.7	5.2	2.2	2.7	2.0	1.9	2.5	1.9	3.5	2.2	2.6	2.8
--	19	6.3	5.2	2.3	2.6	2.0	2.1	2.6	1.9	3.4	2.2	2.7	2.9
						Plan 34							
16	16	6.3	5.2	2.3	2.6	1.9	2.0	2.4	2.0	3.3	2.2	2.6	2.9
--	19	6.3	4.9	2.4	2.4	1.9	2.1	2.4	2.0	3.3	2.2	2.6	2.8

Table 13

Wave Heights for Plans 35-43 for Test Waves from West-Northwest

swl = +5.0 ft

Test Wave		Wave Height, ft											
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 10	Gage 11	Gage 12	Gage 13
						Plan 35							
16	16	2.6	3.1	1.6	2.3	1.8	2.1	2.0	1.6	7.3	2.5	2.6	2.2
--	19	2.5	3.3	1.6	2.1	1.7	2.0	1.9	1.6	7.0	2.6	2.4	2.2
						Plan 36							
16	16	2.8	4.1	2.1	2.6	1.9	2.0	2.0	1.7	7.2	2.7	2.7	3.1
--	19	2.7	3.9	2.1	2.6	1.8	2.1	2.0	1.7	7.3	2.7	2.8	2.9
						Plan 37							
16	16	2.7	3.1	1.8	2.3	1.7	2.0	2.1	1.6	7.2	2.5	2.5	2.3
--	19	2.4	3.4	1.8	2.3	1.7	1.9	2.0	1.6	7.1	2.4	2.4	2.3
						Plan 38							
16	16	2.9	3.3	1.9	2.6	2.0	2.6	2.2	1.8	7.4	2.8	2.6	2.7
--	19	2.9	3.4	2.2	2.8	2.0	2.6	2.5	1.7	7.5	2.9	2.8	2.7
						Plan 39							
16	16	2.6	3.4	1.9	2.6	1.8	2.5	2.2	1.7	--	2.6	2.6	2.5
--	19	2.6	3.0	1.9	2.3	1.8	2.4	2.0	1.6	6.9	2.5	2.6	2.5
						Plan 40							
16	16	3.0	3.8	2.3	2.8	2.0	2.4	2.4	1.7	7.6	2.8	2.9	2.8
--	19	3.0	3.6	2.2	2.7	2.0	2.4	2.4	1.8	7.4	2.7	2.8	2.8

(Continued)

Table 13 (Concluded)

Test Wave		Wave Height, ft											
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 10	Gage 11	Gage 12	Gage 13
						Plan 41							
16	16	2.6	3.6	2.3	2.7	2.1	2.4	2.5	1.8	7.1	2.7	2.8	2.6
--	19	2.8	3.6	2.2	2.7	2.0	2.6	2.4	1.7	7.4	2.8	2.8	2.7
						Plan 42							
16	16	2.8	3.5	2.2	2.6	2.0	2.5	2.2	1.7	7.4	2.7	2.8	2.6
--	19	2.8	3.3	2.1	2.5	1.8	2.2	2.2	1.7	7.0	2.7	2.7	2.6
						Plan 43							
16	16	2.7	3.3	2.1	2.5	1.9	2.5	2.2	1.7	7.5	2.6	2.6	2.5
--	19	2.6	3.0	1.9	2.5	1.8	2.4	2.3	1.7	7.4	2.6	2.6	2.4
14	10	1.9	2.6	1.5	1.6	1.3	1.5	1.5	1.2	4.8	1.8	1.8	1.7

Table 14

Wave Heights for Plans 44-49 for Test Waves from West-Northwest

swl = +5.0 ft

Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13
							Plan 44							
16	16	1.8	2.6	1.9	2.4	2.3	3.7	2.4	2.7	3.7	8.1	1.9	2.1	1.8
--	19	1.7	2.6	1.9	2.4	2.1	3.7	2.2	2.6	3.5	7.9	1.9	2.0	1.9
							Plan 45							
16	16	1.9	2.9	2.0	2.6	2.4	3.9	2.3	2.7	3.3	7.4	2.1	2.2	2.1
--	19	1.7	2.9	2.0	2.6	2.3	4.0	2.6	2.8	3.3	7.0	2.1	2.2	2.0
							Plan 46							
16	16	2.1	3.3	2.2	2.9	2.6	4.1	2.6	3.0	3.5	7.7	2.4	2.5	2.5
--	19	1.9	3.0	2.4	2.8	2.5	4.2	2.4	2.8	3.5	6.9	2.5	2.6	2.4
							Plan 47							
16	16	2.3	4.2	2.6	3.3	2.7	4.4	2.6	2.9	3.7	7.8	2.4	2.6	2.3
--	19	2.2	4.0	2.5	3.5	2.8	4.5	2.8	3.0	4.1	7.7	2.3	2.6	2.2
							Plan 48							
16	16	2.2	3.7	2.3	2.9	2.6	4.2	2.6	2.8	4.0	7.5	2.3	2.5	2.1
--	19	2.2	3.7	2.4	3.3	2.9	4.5	2.8	2.9	3.9	7.6	2.3	2.5	2.2
							Plan 49							
16	16	2.3	3.6	2.1	2.9	2.7	4.3	2.5	2.8	4.0	7.7	2.3	2.4	2.2
--	19	2.2	3.4	2.2	2.9	2.7	4.3	2.6	2.8	4.0	7.8	2.2	2.5	2.3

Table 15

Wave Heights for Plans 50-53 for Test Waves from West-Northwest

swl = +5.0 ft

Test Wave		Wave Height, ft												
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13
							Plan 50							
16	16	2.5	4.4	2.4	3.0	2.7	4.3	2.6	2.8	3.7	4.7	2.3	--	2.6
--	19	2.6	4.6	2.5	3.2	3.0	4.6	2.7	3.2	4.1	5.1	2.5	--	2.5
							Plan 51							
16	16	2.6	4.3	2.8	3.3	2.7	4.3	2.6	2.8	3.8	4.8	2.4	--	2.5
--	19	2.5	4.5	2.6	3.4	2.8	4.2	2.6	3.1	4.1	5.0	2.4	--	2.5
							Plan 52							
16	16	2.5	3.9	2.7	3.4	2.8	4.3	2.7	2.9	3.7	4.8	2.2	--	2.4
--	19	2.6	4.0	2.8	3.5	2.8	4.3	2.6	3.0	3.9	4.8	2.1	--	2.4
							Plan 53							
16	16	2.5	3.2	2.5	3.7	2.8	4.2	2.6	2.8	3.7	4.7	2.4	2.4	2.5
--	19	2.4	3.6	2.5	3.5	2.8	4.2	2.8	2.9	3.7	4.8	2.3	2.4	2.3

Table 16

Wave Heights for Plans 54-59 for Test Waves from West-Northwest

swl = +5.0 ft

Test Wave		Wave Height, ft												
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13
							Plan 54							
16	16	2.7	4.3	3.4	3.4	2.8	4.2	2.8	2.9	3.8	4.8	2.2	2.6	2.3
--	19	2.6	4.3	3.4	3.6	2.9	4.3	3.0	3.0	3.8	5.3	2.2	2.5	2.4
							Plan 55							
16	16	2.5	4.2	3.0	3.0	2.6	4.3	2.5	2.7	3.7	5.0	2.1	2.4	2.2
--	19	2.6	4.0	3.3	3.1	2.6	4.4	2.7	2.9	4.0	5.2	2.2	2.4	2.3
							Plan 56							
16	16	2.6	4.3	3.5	3.3	2.8	4.3	2.7	2.8	3.8	5.1	2.2	2.4	2.1
--	19	2.5	4.0	3.4	3.5	2.8	4.2	2.6	2.9	3.8	4.8	2.2	2.3	2.1
							Plan 57							
16	16	2.3	3.9	2.9	2.9	2.4	3.9	2.3	2.6	3.5	4.5	2.0	2.2	2.1
--	19	2.5	3.9	3.1	3.1	2.6	4.1	2.5	2.7	3.7	4.8	2.0	2.3	2.0
							Plan 58							
16	16	2.5	3.7	2.9	2.9	2.5	3.9	2.4	2.6	3.8	4.6	2.0	2.3	2.1
--	19	2.7	4.0	3.1	3.3	2.9	4.1	2.6	3.1	3.8	5.0	2.3	2.5	2.3
							Plan 59							
16	16	2.7	4.8	2.4	3.4	3.2	5.7	3.1	3.2	--	5.7	2.1	2.6	8.0
--	19	2.5	4.5	2.3	3.4	3.1	5.5	3.1	3.3	--	5.9	2.0	2.5	8.3

Table 17

Wave Heights for Plan 47

swl = +5.0 ft

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13
West-northwest	6	7	0.6	0.7	0.5	0.5	0.6	1.2	0.4	0.5	1.0	2.4	0.6	0.6	0.3
	8	7	0.8	1.0	0.6	0.6	0.7	1.3	0.5	0.6	1.1	2.9	0.8	0.8	0.4
	10	7	0.8	1.1	0.6	0.7	0.8	1.3	0.6	0.6	1.2	3.0	0.8	0.8	0.5
	--	13	1.7	3.4	1.8	2.1	1.7	2.6	2.0	1.7	2.4	5.2	1.4	1.6	1.0
	12	7	1.0	1.8	1.0	1.1	1.0	1.7	1.0	1.0	1.4	3.7	0.9	1.0	0.7
	--	13	2.0	3.7	2.2	2.3	2.3	3.3	2.3	2.1	2.7	6.4	1.8	2.0	1.3
	14	10	1.6	2.3	1.4	1.7	1.6	2.4	1.5	1.6	2.2	5.3	1.4	1.6	1.1
	--	16	2.2	3.5	2.2	2.7	2.6	3.6	2.4	2.5	3.2	7.0	2.0	2.2	1.4
	16	16	2.6	4.2	2.6	3.3	2.7	4.4	2.6	2.9	3.7	7.8	2.4	2.6	2.5
	--	19	2.5	4.0	2.5	3.5	2.8	4.5	2.8	3.0	4.1	7.7	2.5	2.6	2.3
West	6	10	0.8	0.9	0.6	0.7	0.8	1.4	0.6	0.7	1.2	2.5	0.8	0.9	0.4
	8	10	1.0	1.4	0.7	0.8	1.0	1.6	0.7	0.8	1.5	3.4	1.0	1.0	0.5
	10	10	1.2	1.9	1.0	1.2	1.2	1.9	1.1	1.1	1.9	4.1	1.1	1.2	0.8
	--	19	1.8	3.8	1.7	2.1	2.0	3.0	2.0	1.9	2.9	6.0	1.7	1.9	1.3
	12	16	1.8	3.9	1.9	2.3	2.0	3.0	2.1	2.0	2.7	6.3	1.7	2.0	1.3
	--	19	1.9	4.1	1.9	2.2	2.1	3.1	2.2	2.1	2.9	6.2	1.8	2.0	1.2
	14	16	1.7	3.3	1.8	2.3	1.8	2.7	2.1	2.0	2.9	5.7	1.6	1.8	1.2
	16	19	2.0	3.8	1.9	2.4	2.0	3.1	2.1	2.2	2.9	5.9	1.6	1.9	1.5
West-southwest	6	10	0.7	0.9	0.5	0.6	0.7	1.2	0.6	0.7	1.1	2.2	0.7	0.7	0.4
	8	10	0.9	1.3	0.7	0.9	0.9	1.5	0.8	1.0	1.5	2.8	0.8	0.8	0.5
	--	16	1.4	2.3	1.3	1.4	1.3	2.1	1.4	1.3	2.1	3.9	1.2	1.3	0.8
	10	10	1.2	2.0	1.1	1.3	1.2	1.9	1.2	1.2	2.0	3.6	1.1	1.4	0.8
	--	25	2.0	3.6	1.9	2.4	2.3	3.4	2.1	2.1	3.1	6.1	1.8	2.0	1.4
	12	16	1.9	3.6	2.0	2.3	2.0	3.0	2.1	2.2	3.1	5.9	1.6	1.9	1.2
	--	19	1.9	3.8	2.3	2.5	2.1	3.1	2.2	2.2	3.3	6.6	1.9	2.0	1.3
	14	16	2.0	3.3	2.3	2.4	2.1	3.1	2.2	2.1	3.3	6.4	1.9	2.1	1.3
	16	19	1.9	3.1	2.1	2.4	2.0	3.2	2.2	2.1	3.3	6.2	1.7	1.9	1.3

(Continued)

Table 17 (Concluded)

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13
Southwest	6	10	0.5	0.6	0.4	0.5	0.5	1.0	0.5	0.6	0.9	1.7	0.4	0.5	0.3
	8	7	0.7	1.4	0.6	0.7	0.8	1.2	0.7	0.9	1.3	2.2	0.7	0.7	0.5
	--	13	0.9	1.9	1.0	1.0	1.0	1.5	0.8	1.0	1.6	2.9	0.9	1.0	0.6
	10	7	1.0	1.6	1.0	1.1	1.0	1.5	0.9	1.0	1.6	3.0	0.9	1.0	0.6
	--	16	1.4	2.6	1.4	1.7	1.5	2.1	1.4	1.4	2.2	4.3	1.3	1.3	1.0
	12	10	1.5	2.7	1.7	1.9	1.5	2.3	1.5	1.5	2.5	4.7	1.3	1.5	1.0
	--	19	1.7	2.8	1.7	2.1	1.7	2.6	1.9	1.8	2.7	5.2	1.5	1.7	1.2
	14	16	1.7	3.4	2.2	2.5	1.7	2.6	1.9	1.9	3.0	5.0	1.7	1.8	2.0
	16	19	1.7	2.9	1.8	2.1	1.9	2.6	1.9	2.0	2.8	5.0	1.6	1.8	1.7
South-southwest	6	7	0.4	0.6	0.3	0.4	0.4	0.7	0.4	0.5	0.8	1.3	0.3	0.3	0.3
	8	7	0.5	0.9	0.4	0.5	0.5	0.8	0.5	0.6	1.0	1.5	0.4	0.5	0.4
	10	7	0.7	1.0	0.6	0.7	0.7	1.1	0.7	0.6	1.1	1.8	0.6	0.6	0.6
	--	19	1.4	3.3	1.7	1.9	1.6	2.2	1.6	1.5	2.5	4.3	1.5	1.4	1.5
	12	7	0.9	1.2	1.0	1.0	0.9	1.5	0.8	0.9	1.5	2.4	0.9	0.9	0.8
	--	16	1.7	3.0	1.8	2.0	1.7	2.5	1.8	1.7	2.6	4.8	1.5	1.6	1.5
	14	10	1.3	2.1	1.5	1.8	1.4	2.1	1.4	1.5	2.2	3.7	1.3	1.2	1.4
	--	16	1.8	3.0	2.1	2.2	1.7	2.6	1.8	1.8	3.0	4.8	1.7	1.8	1.9
	16	16	1.7	2.9	1.7	2.1	1.8	2.6	1.9	2.0	2.8	4.9	1.7	1.8	1.7

Photo 1. Typical wave patterns for existing conditions; 8-sec, 7-ft test waves from west-northwest; swl = +5.0 ft

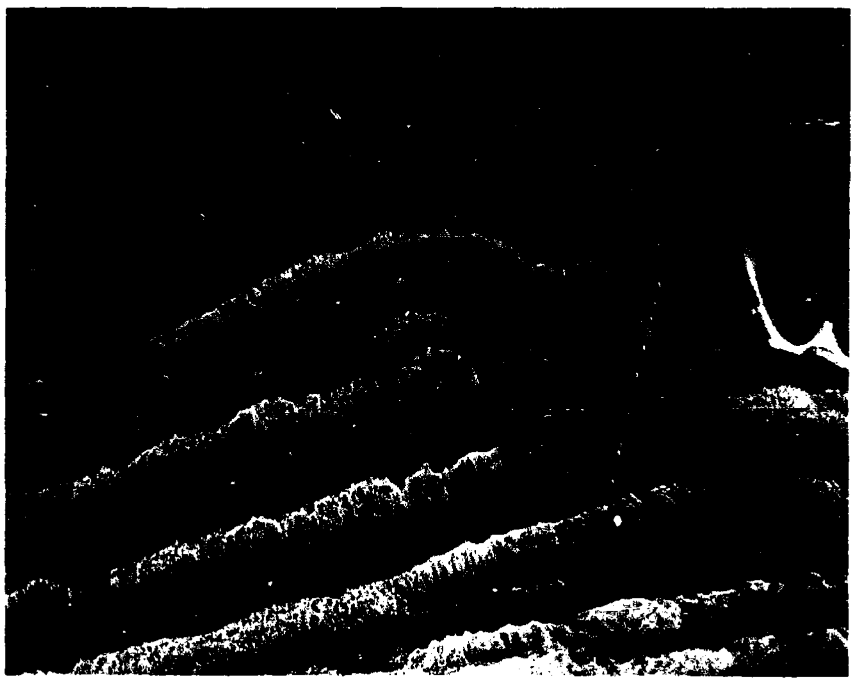


Photo 2. Typical wave patterns for existing conditions; 12-sec, 13-ft test waves from west-northwest; swl = +5.0 ft

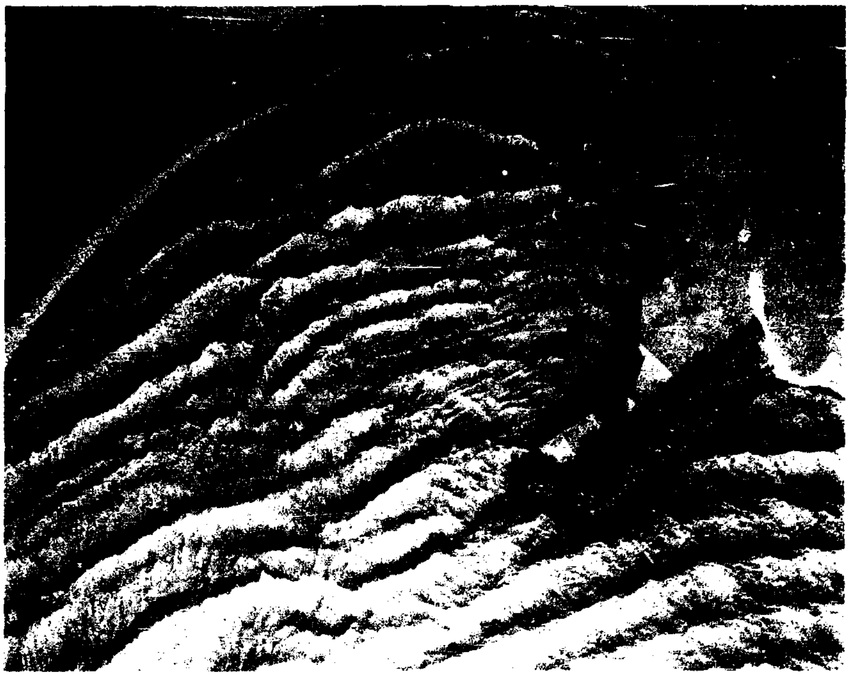


Photo 3. Typical wave patterns for existing conditions; 10-sec, 10-ft test waves from west; swl = +5.0 ft

Photo 4. Typical wave patterns for existing conditions; 14-sec, 16-ft test waves from west; swl = +5.0 ft

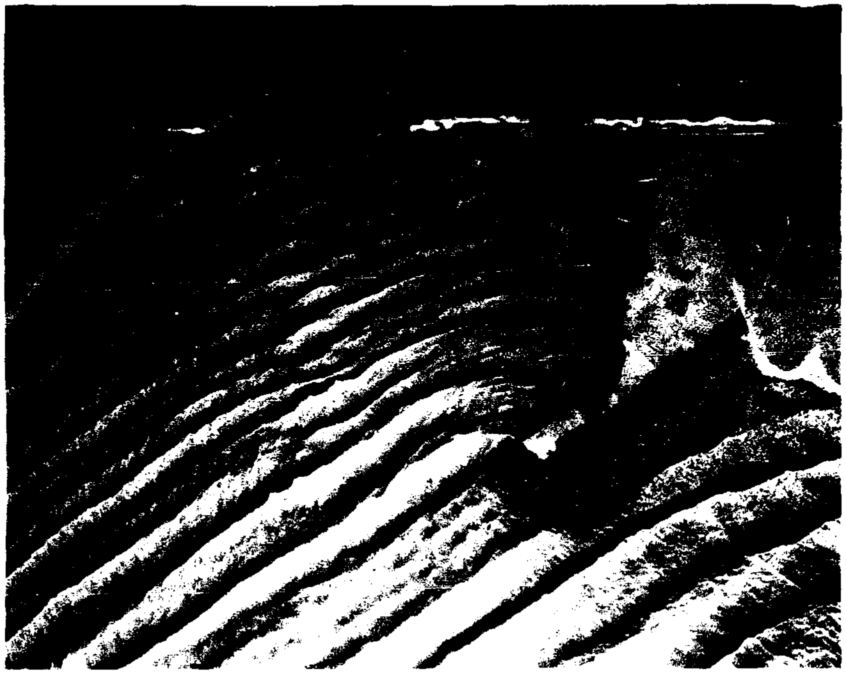


Photo 5. Typical wave patterns for existing conditions; 8-sec, 10-ft test waves from west-southwest; swl = +5.0 ft

Photo 6. Typical wave patterns for existing conditions; 16-sec, 19-ft test waves from west-southwest; swl = +5.0 ft

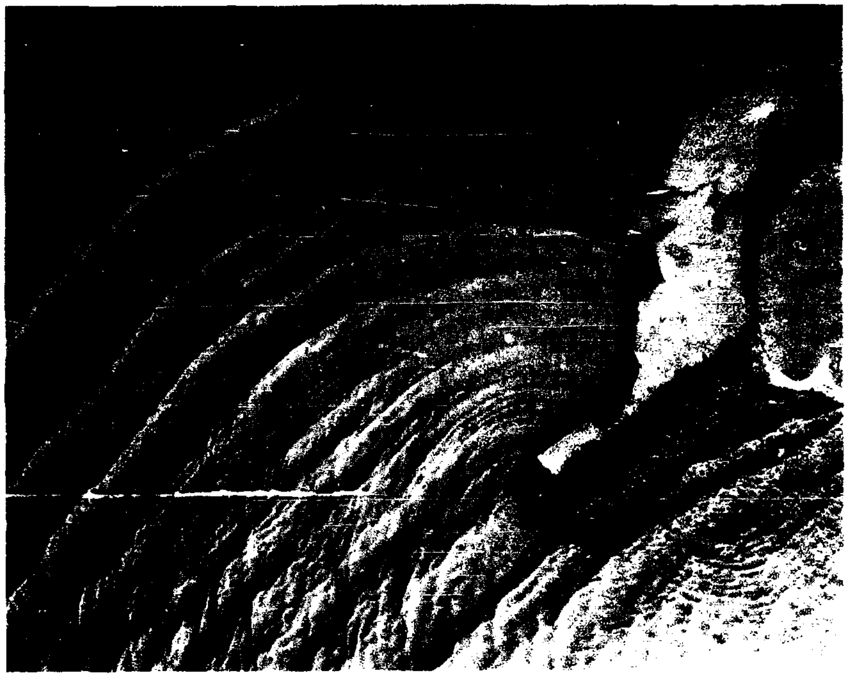


Photo 7. Typical wave patterns for existing conditions; 10-sec, 7-ft test waves from southwest; swl = +5.0 ft

Photo 8. Typical wave patterns for existing conditions; 12-sec, 19-ft test waves from southwest; swl = +5.0 ft

Photo 9. Typical wave patterns for exisitng conditions; 6-sec, 7-ft test waves from south-southwest; swl = +5.0 ft

Photo 10. Typical wave patterns for existing conditions; 12-sec, 16-ft test waves from south-southwest; swl = +5.0 ft

a. 8-sec, 7-ft test waves
(Test 1 of a series)

b. 10-sec, 13-ft test waves
(Test 2 of a series)

c. 14-sec, 16-ft test waves
(Test 3 of a series)

d. 16-sec, 19-ft test waves
(Test 4 of a series)

Photo 11. General movement of tracer material and subsequent deposits for existing conditions for test waves from west-northwest; swl = +3.2 ft

a. 6-sec, 10-ft test waves (Test 1 of a series)

b. 12-sec, 16-ft test waves (Test 2 of a series)

c. 10-sec, 19-ft test waves (Test 3 of a series)

d. 16-sec, 19-ft test waves (Test 4 of a series)

Photo 12. General movement of tracer material and subsequent deposits for existing conditions for test waves from west; swl = +3.2 ft

a. 6-sec, 10-ft test waves
(Test 1 of a series)

b. 12-sec, 19-ft test waves
(Test 2 of a series)

c. 10-sec, 25-ft test waves
(Test 3 of a series)

d. 16-sec, 19-ft test waves
(Test 4 of a series)

Photo 13. General movement of tracer material and subsequent deposits for existing conditions for test waves from west-southwest; swl = +3.2 ft

Photo 15. Typical wave patterns for Plan 1; 8-sec, 7-ft test waves from west-northwest; swl = +5.0 ft

Photo 16. Typical wave patterns for Plan 1; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 17. Typical wave patterns for Plan 1; 10-sec, 10-ft test waves from west; swl = +5.0 ft

Photo 18. Typical wave patterns for Plan 1; 14-sec, 16-ft test waves from west; swl = +5.0 ft

Photo 19. Typical wave patterns for Plan 1; 8-sec, 10-ft test waves from west-southwest; swl = +5.0 ft

Photo 20. Typical wave patterns for Plan 1; 16-sec, 19-ft test waves from west-southwest; swl = +5.0 ft

a. 8-sec, 7-ft test waves
(Test 1 of a series)

b. 10-sec, 13-ft test waves
(Test 2 of a series)

c. 14-sec, 16-ft test waves
(Test 3 of a series)

d. 16-sec, 19-ft test waves
(Test 4 of a series)

Photo 21. General movement of tracer material and subsequent deposits for Plan 1 for test waves from west-northwest; swl = +3.2 ft

a. 6-sec, 10-ft test waves
(Test 1 of a series)

b. 12-sec, 16-ft test waves
(Test 2 of a series)

c. 10-sec, 19-ft test waves
(Test 3 of a series)

d. 16-sec, 19-ft test waves
(Test 4 of a series)

Photo 22. General movement of tracer material and subsequent deposits for Plan 1 for test waves from west; swl = +3.2 ft

a. 6-sec, 10-ft test waves
(Test 1 of a series)

b. 12-sec, 19-ft test waves
(Test 2 of a series)

c. 10-sec, 25-ft test waves
(Test 3 of a series)

d. 16-sec, 19-ft test waves
(Test 4 of a series)

Photo 23. General movement of tracer material and subsequent deposits for Plan 1 for test waves from west-southwest; swl = +3.2 ft

Photo 24. Typical wave patterns for Plan 2; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 25. Typical wave patterns for Plan 3; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

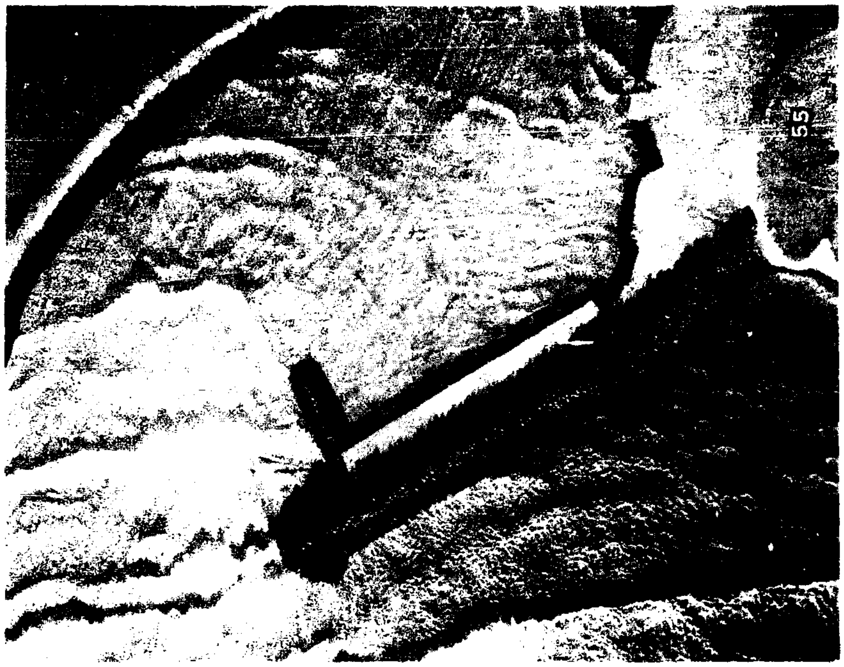


Photo 26. Typical wave patterns for Plan 4; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 27. Typical wave patterns for Plan 5; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 28. Typical wave patterns for Plan 6; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 29. Typical wave patterns for Plan 7; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 30. Typical wave patterns for Plan 8; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 31. Typical wave patterns for Plan 9; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 32. Typical wave patterns for Plan 10; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 33. Typical wave patterns for Plan 11; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 34. Typical wave patterns for Plan 12; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 35. Typical wave patterns for Plan 13; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 36. Typical wave patterns for Plan 14; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 37. Typical wave patterns for Plan 15; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 38. Typical wave patterns for Plan 16; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 39. Typical wave patterns for Plan 17; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 40. Typical wave patterns for Plan 18; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 41. Typical wave patterns for Plan 19; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 42. Typical wave patterns for Plan 20; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 43. Typical wave patterns for Plan 21; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

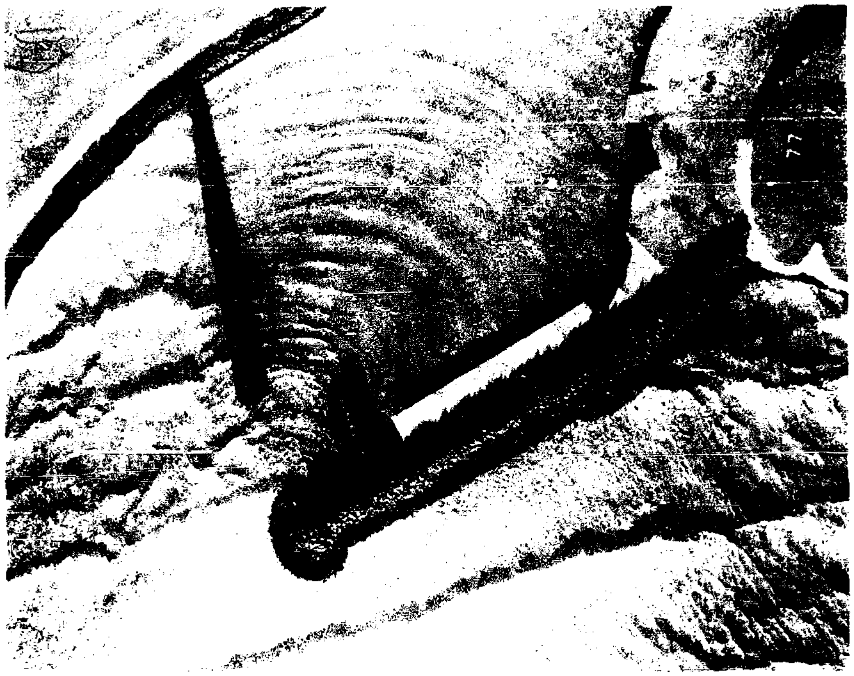


Photo 44. Typical wave patterns for Plan 22; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

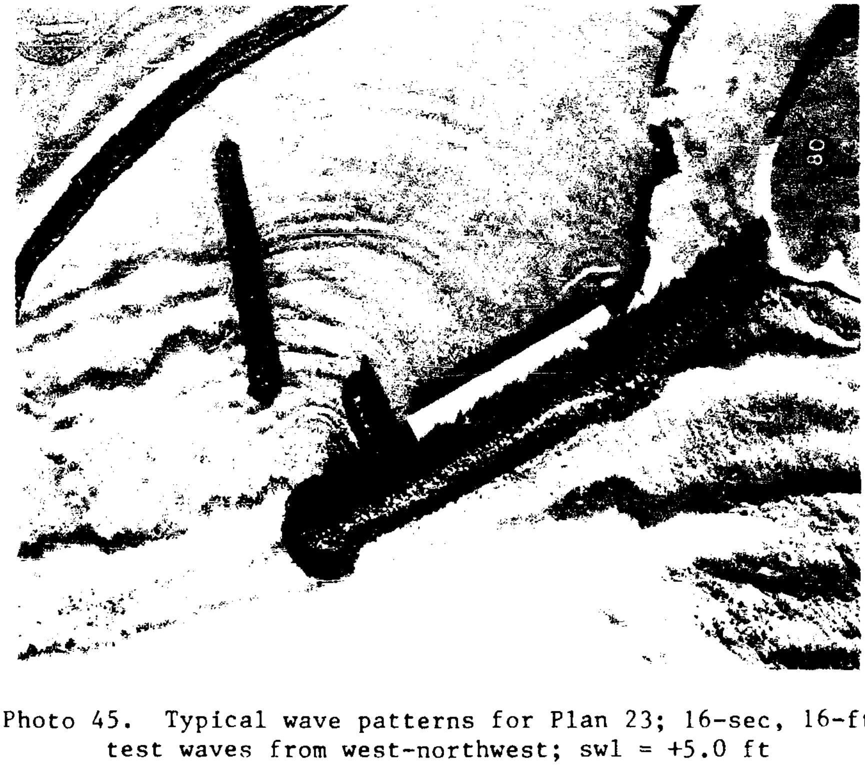


Photo 45. Typical wave patterns for Plan 23; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

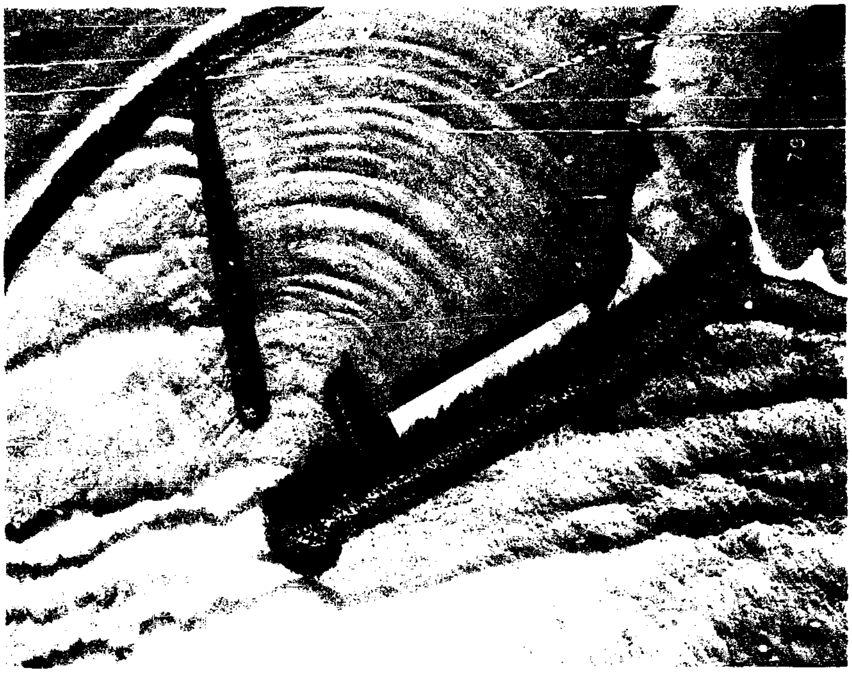


Photo 46. Typical wave patterns for Plan 24; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 47. Typical wave patterns for Plan 25; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

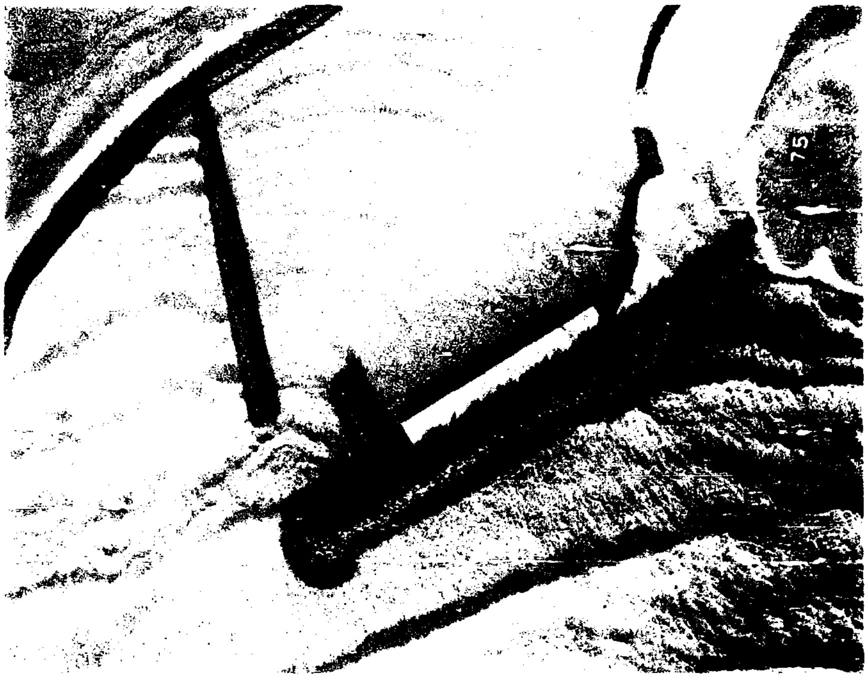


Photo 48. Typical wae patterns for Plan 26; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 49. Typical wave patterns for Plan 27; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 50. Typical wave patterns for Plan 28; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 51. Typical wave patterns for Plan 29; 16-sec, 16-ft test waves from west-northwest; swl + +5.0 ft

Photo 52. Typical wave patterns for Plan 30; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

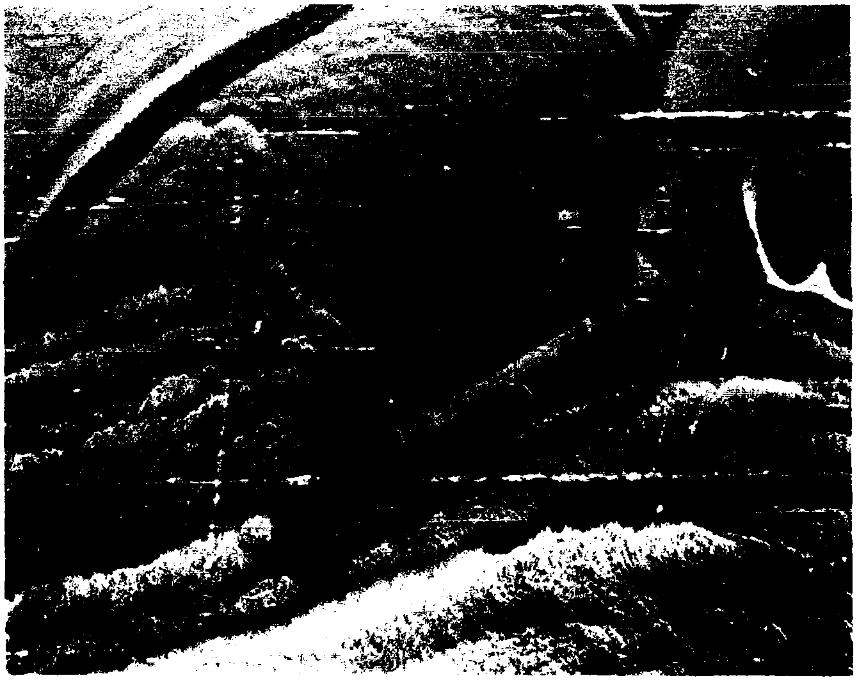


Photo 53. Typical wave patterns for Plan 31; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 54. Typical wave patterns for Plan 32; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 55. Typical wave patterns for Plan 33; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 56. Typical wave patterns for Plan 34; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 57. Typical wave patterns for Plan 35; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 58. Typical wave patterns for Plan 36; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 59. Typical wave patterns for Plan 37; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 60. Typical wave patterns for Plan 38; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 61. Typical wave patterns for Plan 39; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 62. Typical wave patterns for Plan 40; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 63. Typical wave patterns for Plan 41; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 64. Typical wave patterns for Plan 42; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 65. Typical wave patterns for Plan 43; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 66. Typical wave patterns for Plan 44; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 67. Typical wave patterns for Plan 45; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 68. Typical wave patterns for Plan 46; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 69. Typical wave patterns for Plan 47; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 70. Typical wave patterns for Plan 48; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 71. Typical wave patterns for Plan 49; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 72. Typcial wave patterns for Plan 50; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 73. Typical wave patterns for Plan 51; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 74. Typical wave patterns for Plan 52; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 75. Typical wave patterns for Plan 53; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

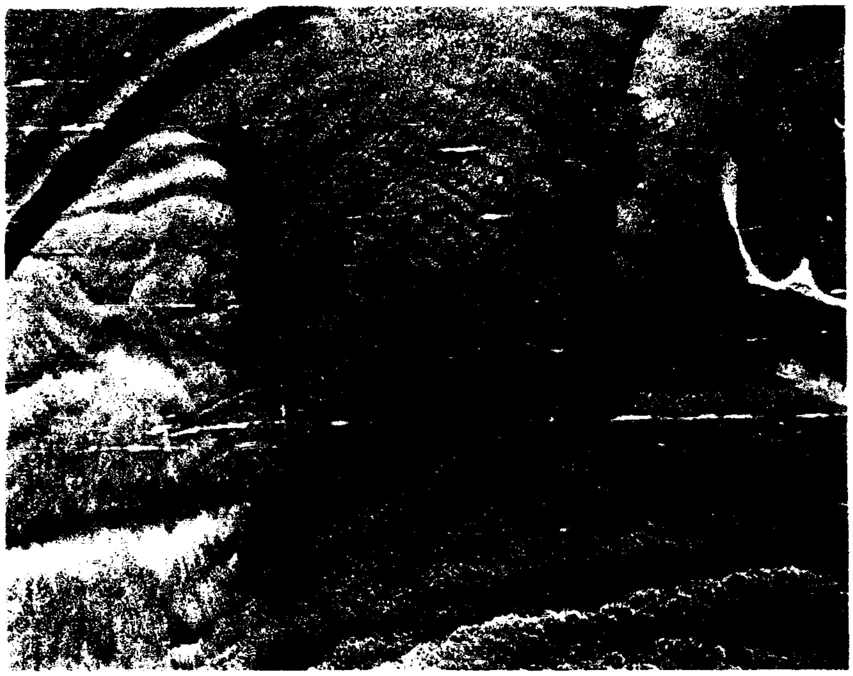


Photo 76. Typical wave patterns for Plan 54; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

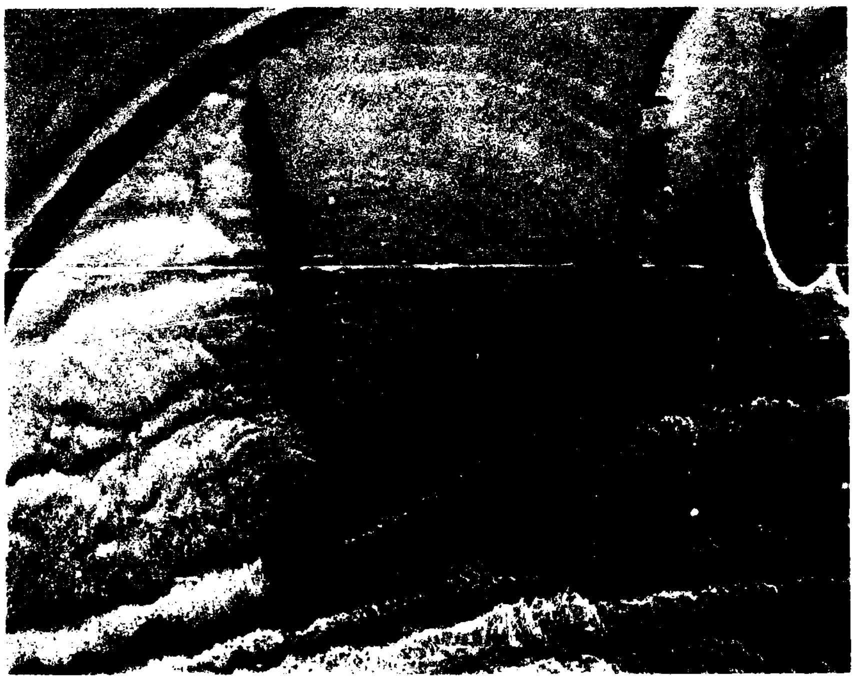


Photo 77. Typical wave patterns for Plan 55; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

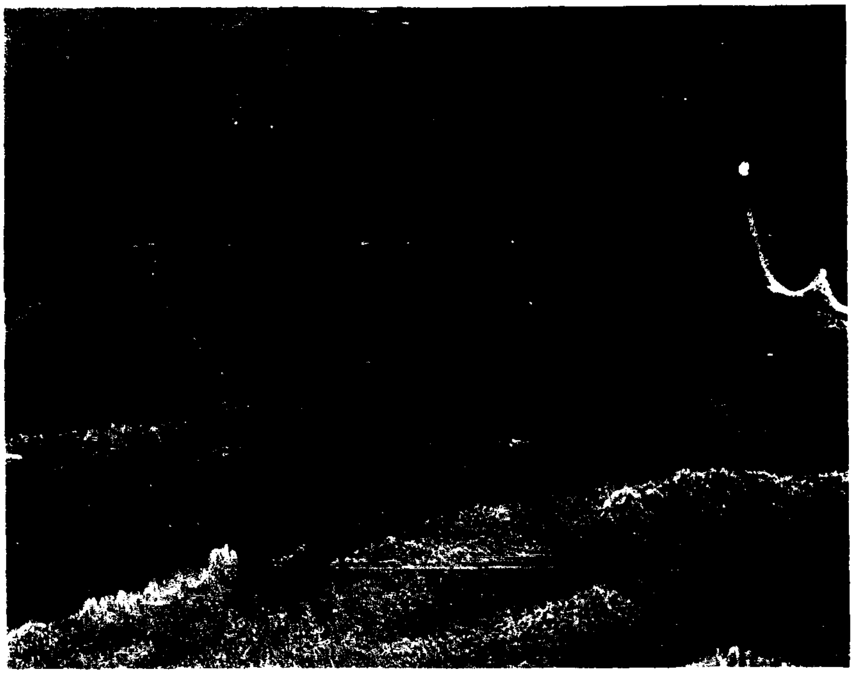


Photo 78. Typical wave patterns for Plan 56; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 79. Typical wave patterns for Plan 57; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 80. Typical wave patterns for Plan 58; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 81. Typical wave patterns for Plan 59; 16-sec, 16-ft test waves from west-northwest; swl = +5.0 ft

Photo 82. Typical wave patterns for Plan 47; 8-sec, 7-ft test waves from west-northwest; swl = +5.0 ft

Photo 83. Typical wave patterns for Plan 47; 12-sec, 13-ft test waves from west-northwest; swl = +5.0 ft

Photo 84. Typical wave patterns for Plan 47; 10-sec, 10-ft test waves from west; swl = +5.0 ft

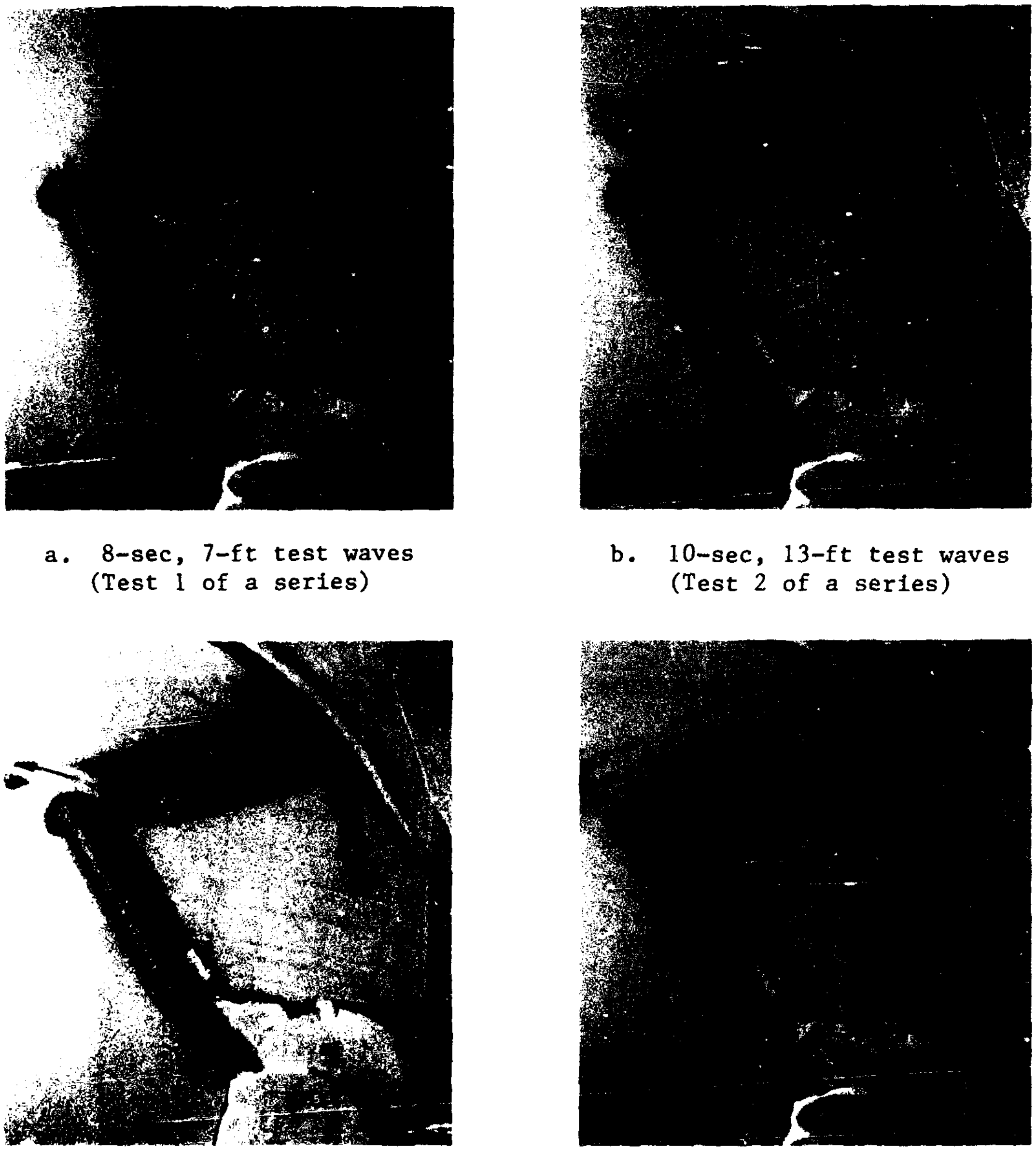
Photo 85. Typical wave patterns for Plan 47; 14-sec, 16-ft test waves from west; swl = + 5.0 ft

Photo 86. Typical wave patterns for Plan 47; 8-sec, 10-ft test waves from west-southwest; swl = +5.0 ft

Photo 87. Typical wave patterns for Plan 47; 16-sec, 19-ft test waves from west-southwest; swl = +5.0 ft

Photo 88. Typical wave patterns for Plan 47; 6-sec, 7-ft test waves from south-southwest; swl = +5.0 ft

Photo 89. Typical wave patterns for Plan 47; 12-sec, 16-ft test waves from south-southwest; swl = +5.0 ft



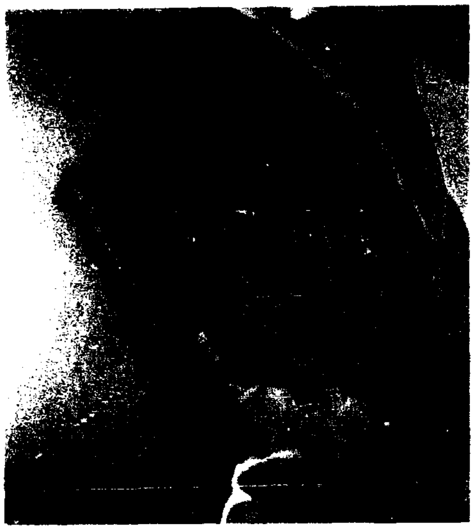
a. 8-sec, 7-ft test waves
(Test 1 of a series)

b. 10-sec, 13-ft test waves
(Test 2 of a series)

c. 14-sec, 16-ft test waves
(Test 3 of a series)

d. 16-sec, 19-ft test waves
(Test 4 of a series)

Photo 90. General movement of tracer material and subsequent deposits for Plan 47 for test waves from west-northwest; swl = +3.2 ft



a. 6-sec, 10-ft test waves
(Test 1 of a series)

b. 12-sec, 16-ft test waves
(Test 2 of a series)

c. 10-sec, 19-ft test waves
(Test 3 of a series)

d. 16-sec, 19-ft test waves
(Test 4 of a series)

Photo 91. General movement of tracer material and subsequent deposits for Plan 47 for test waves from west; swl = +3.2 ft

a. 6-sec, 10-ft test waves
(Test 1 of a series)

b. 12-sec, 19-ft test waves
(Test 2 of a series)

c. 10-sec, 25-ft test waves
(Test 3 of a series)

d. 16-sec, 19-ft test waves
(Test 4 of a series)

Photo 92. General movement of tracer material and subsequent deposits for Plan 47 for test waves from west-southwest; swl = +3.2 ft

a. 6-sec, 7-ft test waves
(Test 1 of a series)

b. 12-sec, 16-ft test waves
(Test 2 of a series)

c. 10-sec, 19-ft test waves
(Test 3 of a series)

d. 16-sec, 16-ft test waves
(Test 4 of a series)

Photo 93. General movement of tracer material and subsequent deposits for Plan 47 for test waves from south-southwest; swl = +3.2 ft

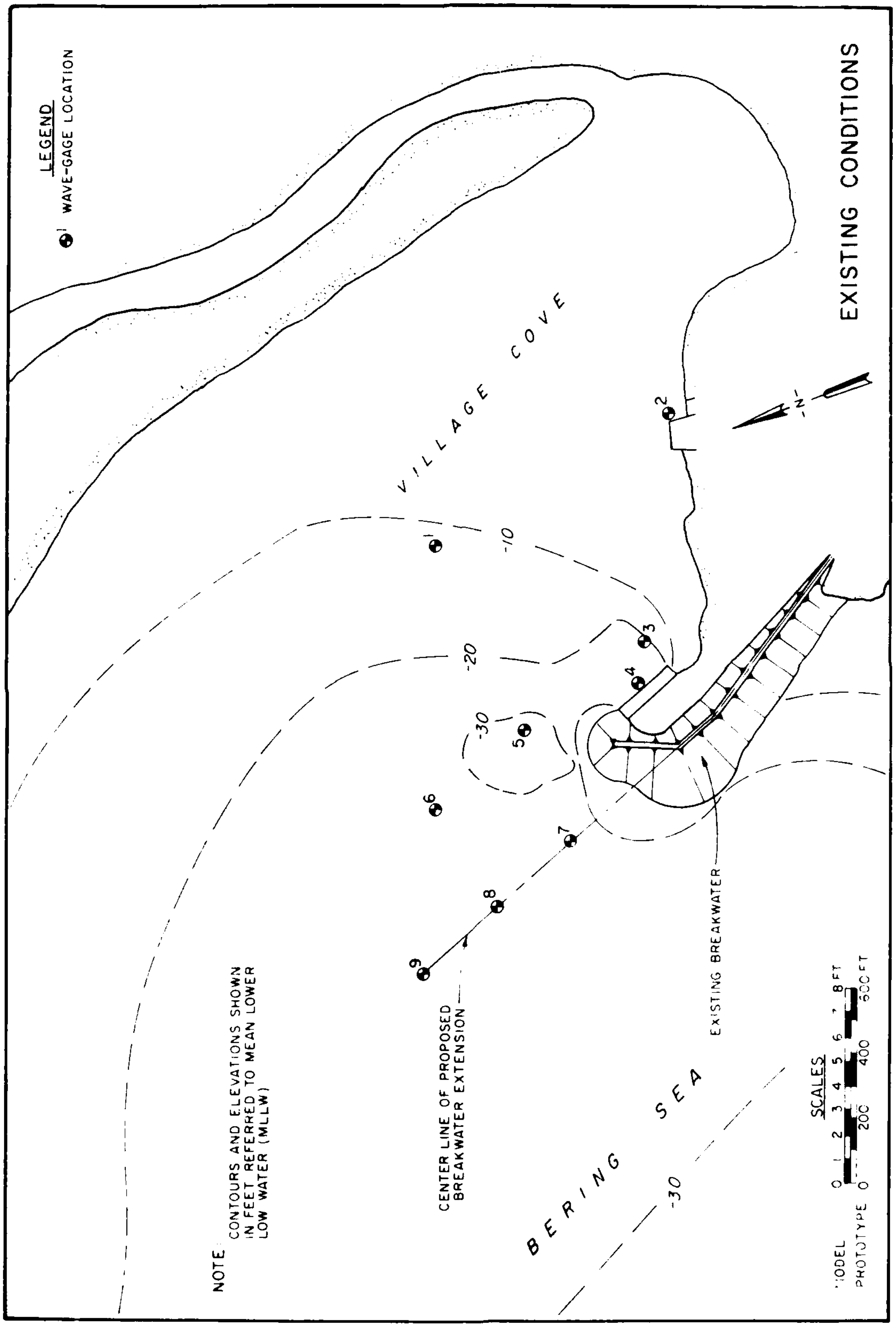

EXISTING CONDITIONS
LEGEND
WAVE-GAGE LOCATION
VILLAGE COVE
BERING SEA
-10
-20
-30
-30
1
2
3
4
5
6
7
8
9
N
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
CENTER LINE OF PROPOSED BREAKWATER EXTENSION
EXISTING BREAKWATER
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT

PLATE 1

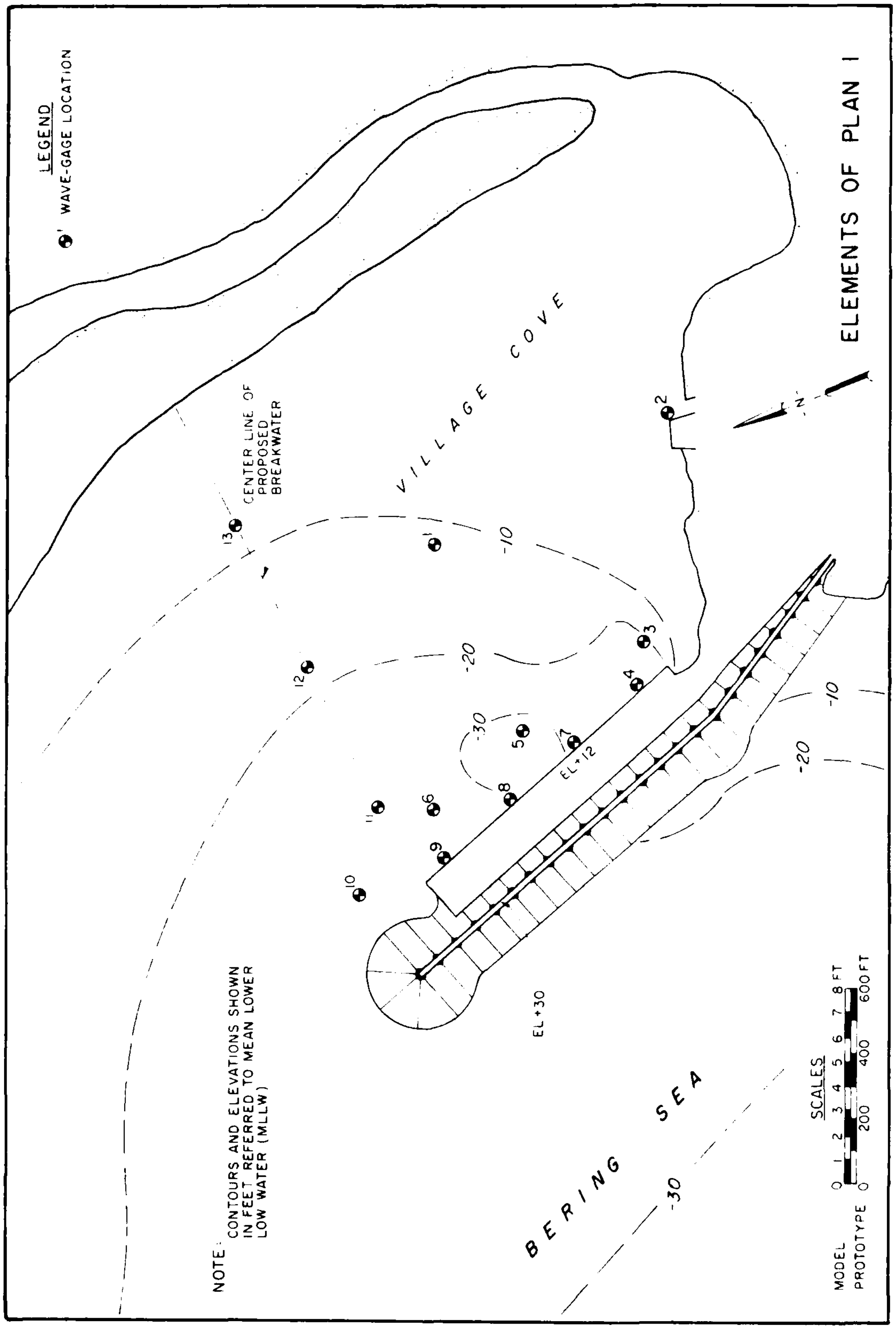

LEGEND
WAVE-GAGE LOCATION
ELEMENTS OF PLAN 1
VILLAGE COVE
CENTER LINE OF PROPOSED BREAKWATER
BERING SEA
EL +12
EL +30
-10
-20
-30
N
1
2
3
4
5
6
7
8
9
10
11
12
13
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT

PLATE 2

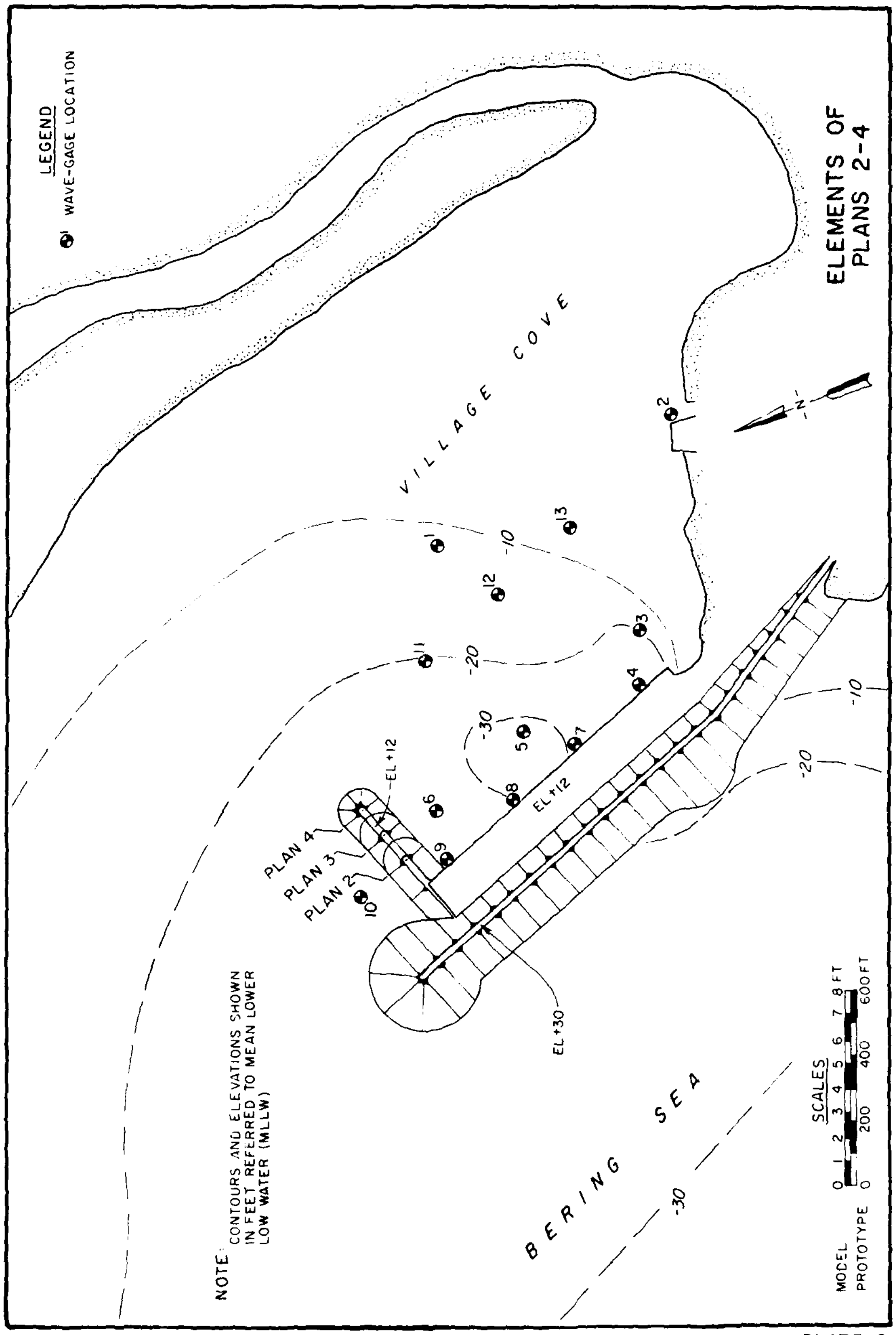
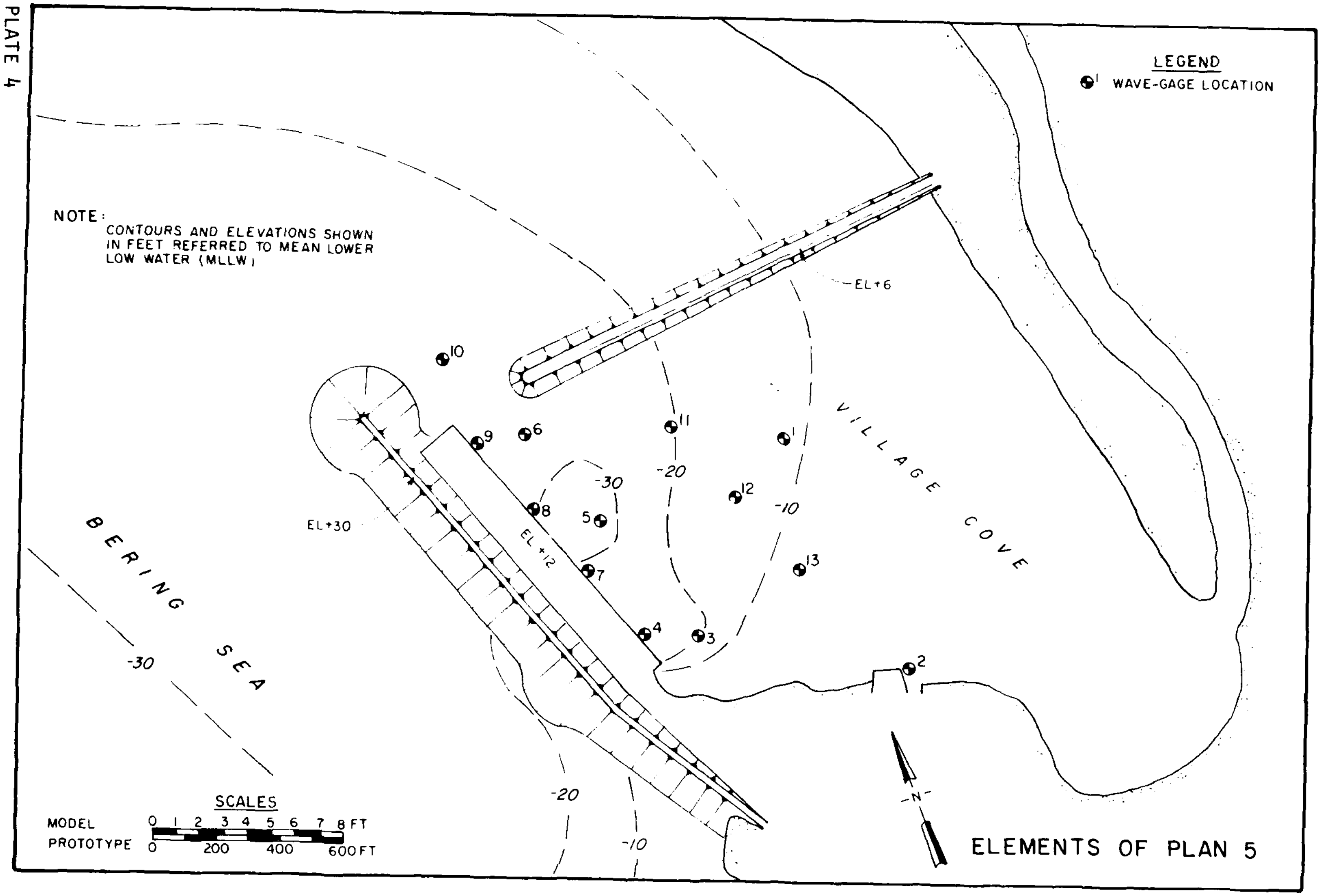
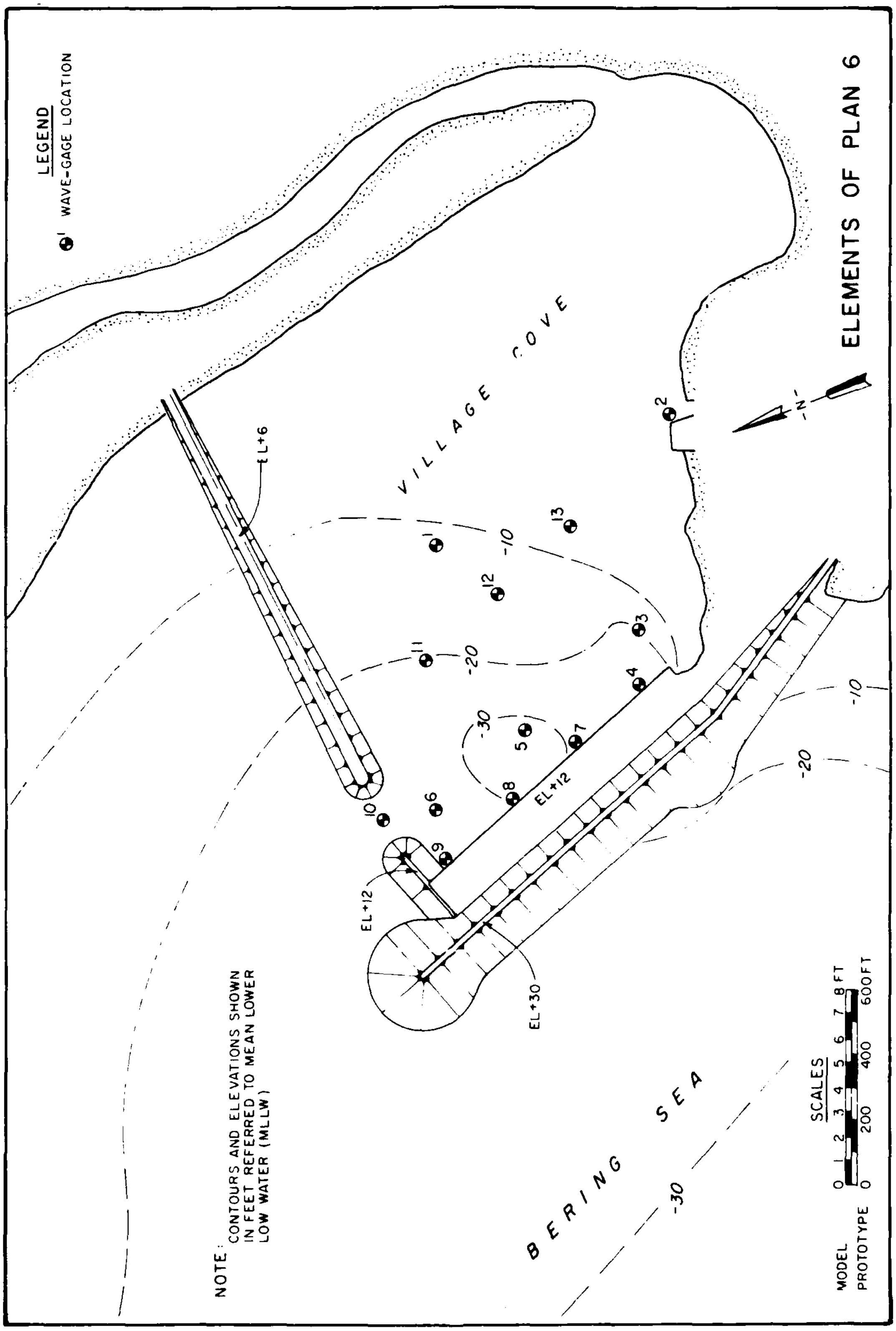

LEGEND
WAVE-GAGE LOCATION
ELEMENTS OF
PLANS 2-4
VILLAGE COVE
BERING SEA
PLAN 4
PLAN 3
PLAN 2
EL +12
EL +30
-10
-20
-30
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL
PROTOTYPE
0 1 2 3 4 5 6 7 8 FT
0 200 400 600 FT
N

PLATE 3



ELEMENTS OF PLAN 5



LEGEND
WAVE-GAGE LOCATION
ELEMENTS OF PLAN 6
VILLAGE COVE
BERING SEA
EL +6
EL +12
EL +12
EL +30
-10
-20
-30
-10
-20
-30
1
2
3
4
5
6
7
8
9
10
11
12
13
N
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT

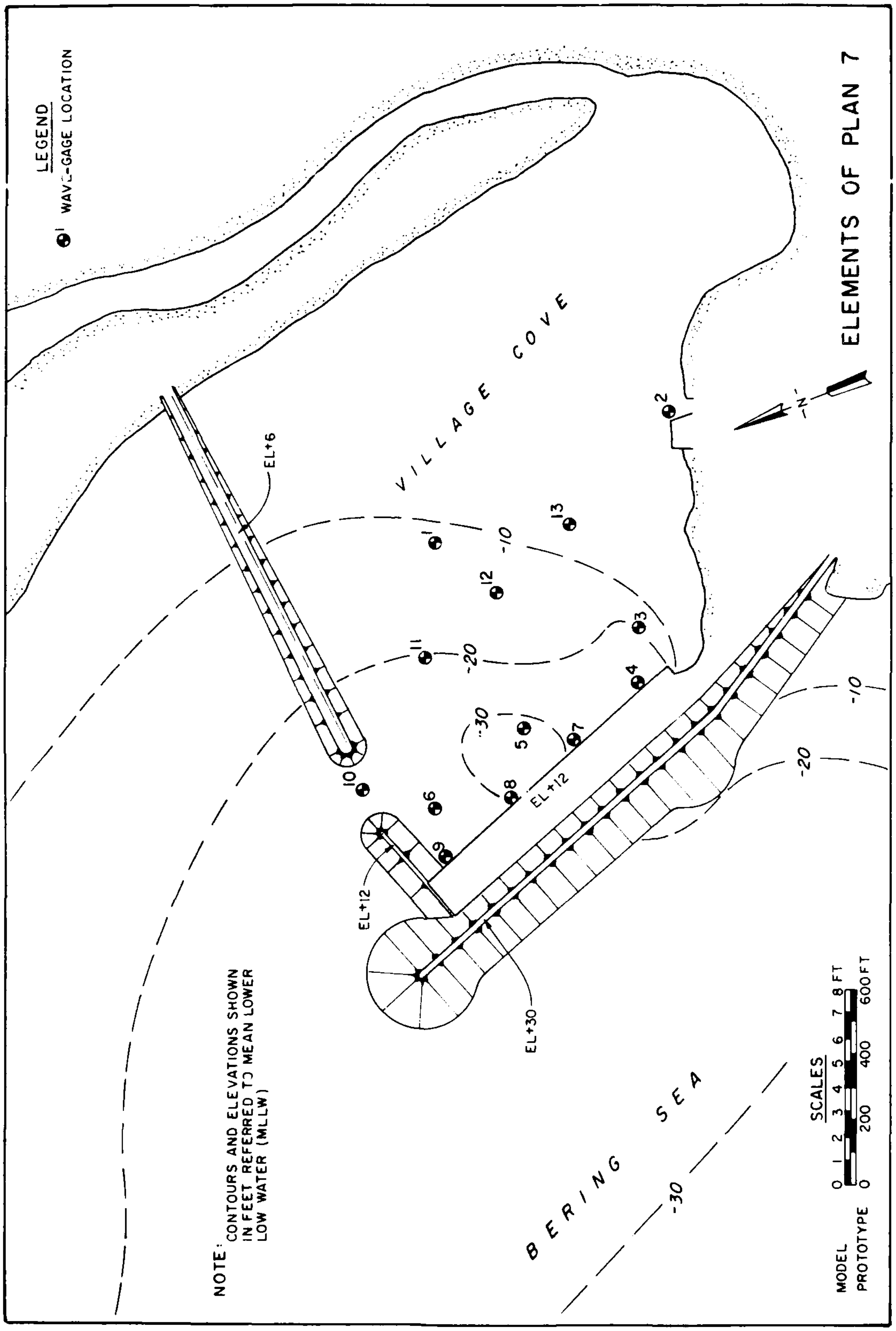
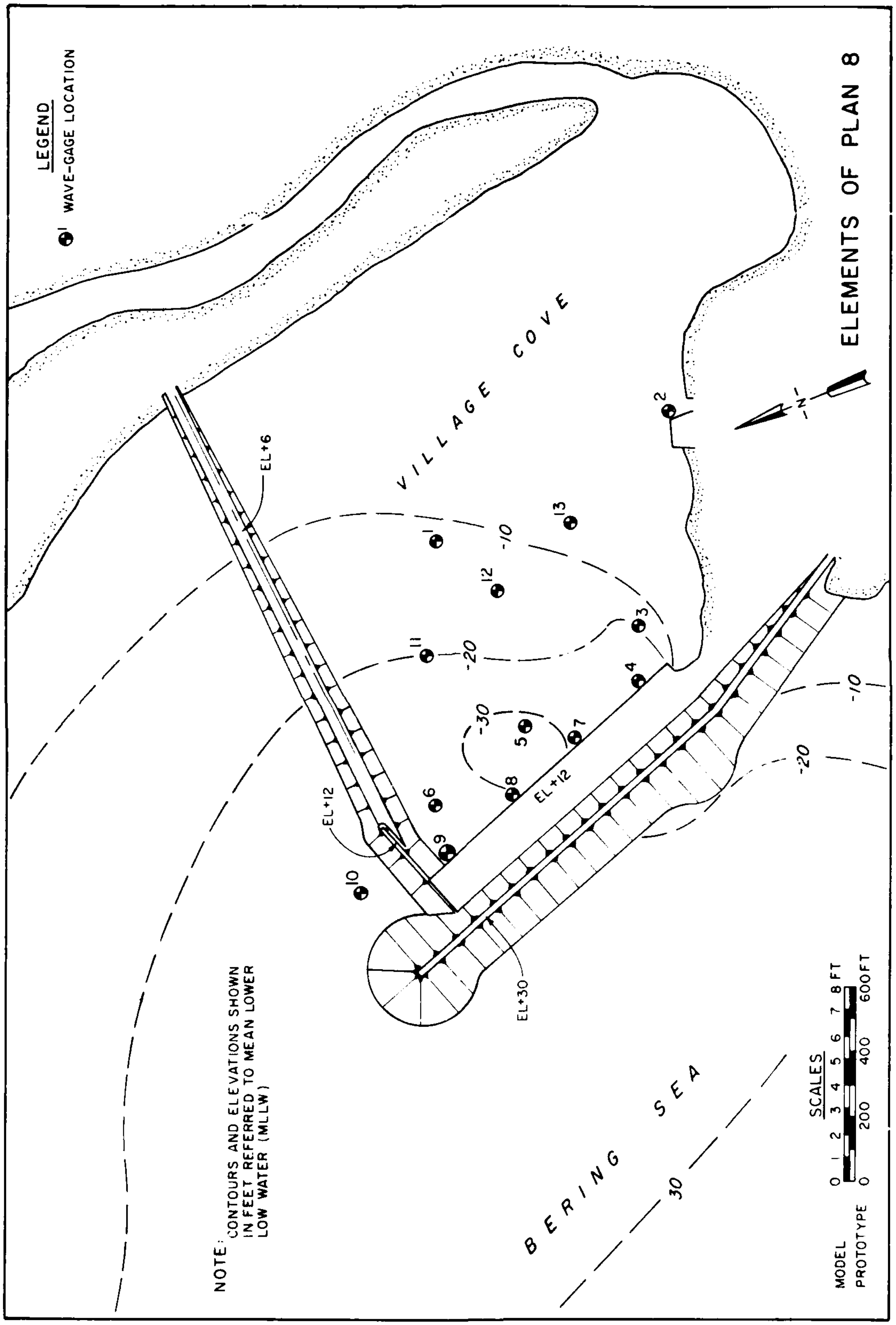
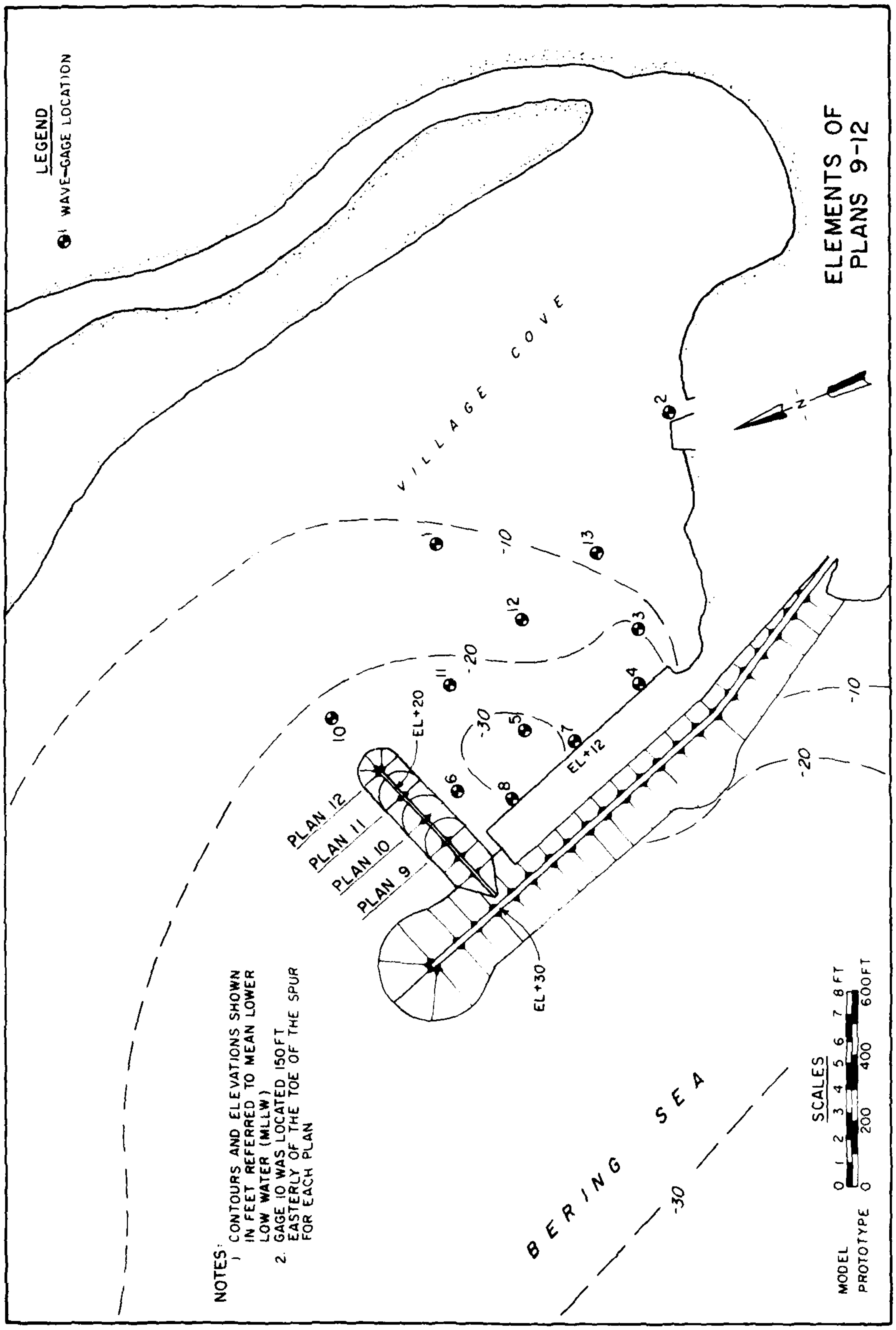

LEGEND
WAVE-GAGE LOCATION
VILLAGE COVE
BERING SEA
EL+6
EL+12
EL+12
EL+30
-10
-20
-30
-10
-20
-30
N
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT
ELEMENTS OF PLAN 7

PLATE 6



ELEMENTS OF PLAN 8



LEGEND
WAVE-GAGE LOCATION
ELEMENTS OF PLANS 9-12
VILLAGE COVE
BERING SEA
PLAN 12
PLAN 11
PLAN 10
PLAN 9
EL+20
EL+12
EL+30
-10
-20
-30
1
2
3
4
5
6
7
8
10
11
12
13
N
NOTES:
1. CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
2. GAGE 10 WAS LOCATED 150 FT EASTERLY OF THE TOE OF THE SPUR FOR EACH PLAN
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT

PLATE 8

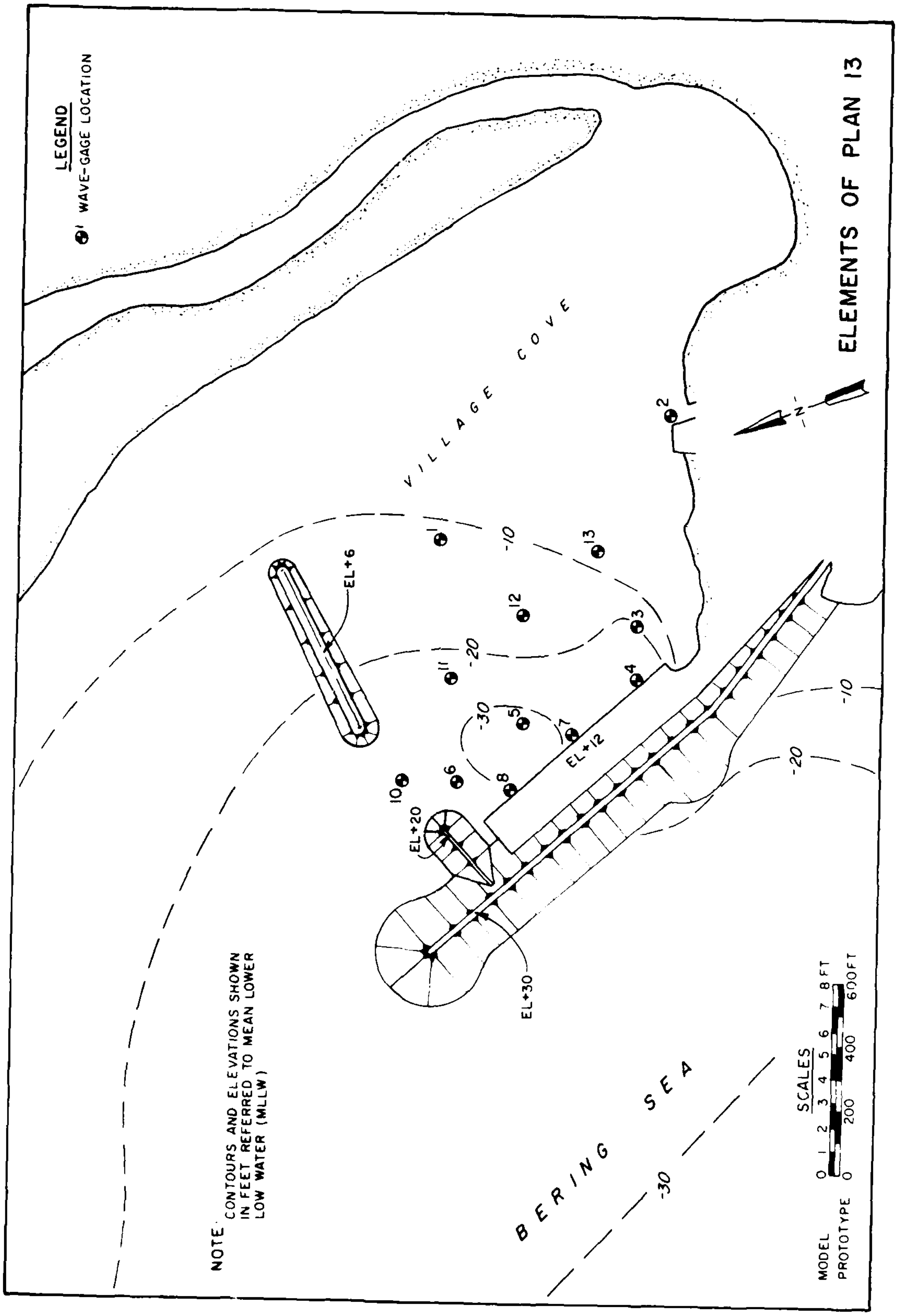
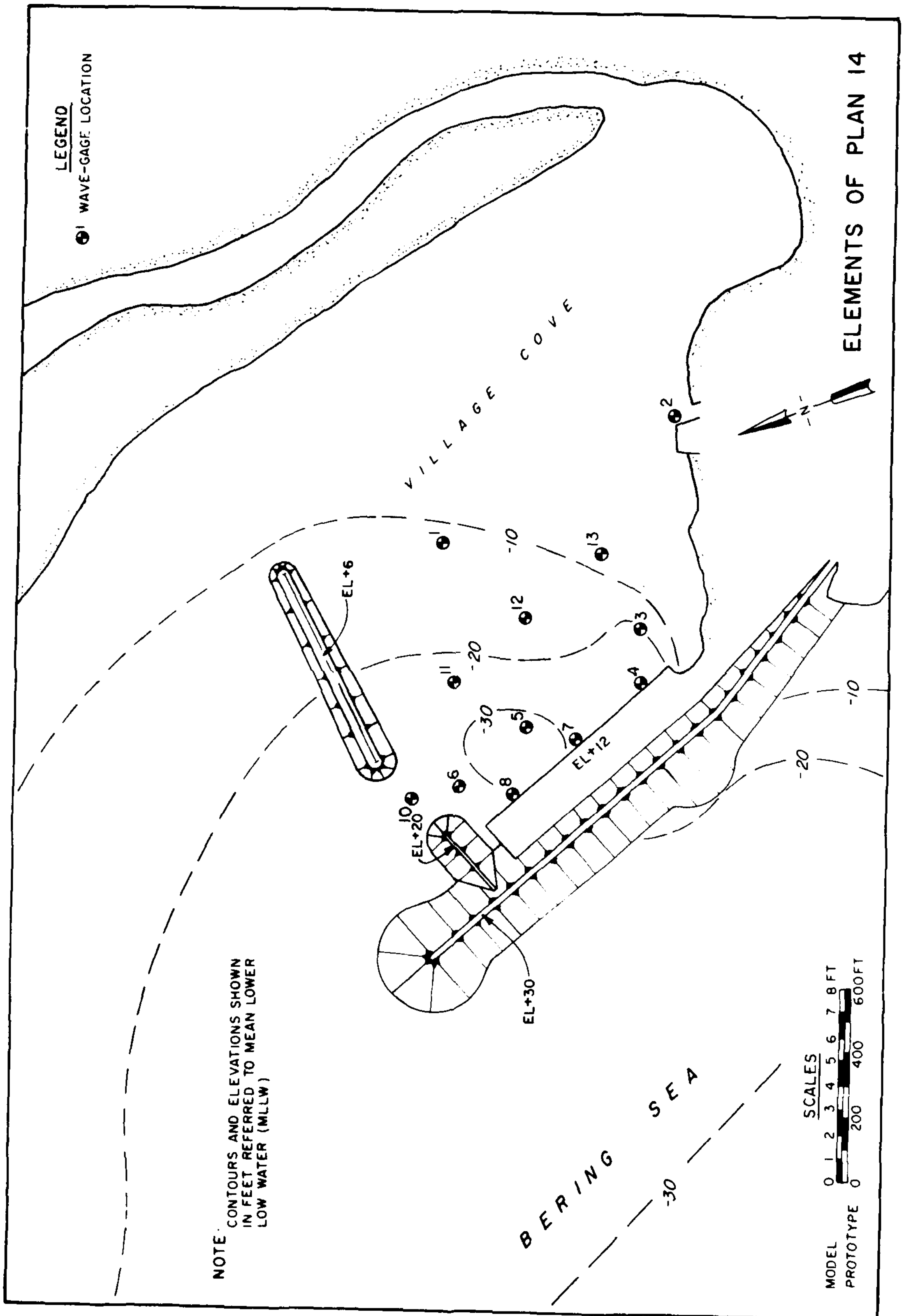
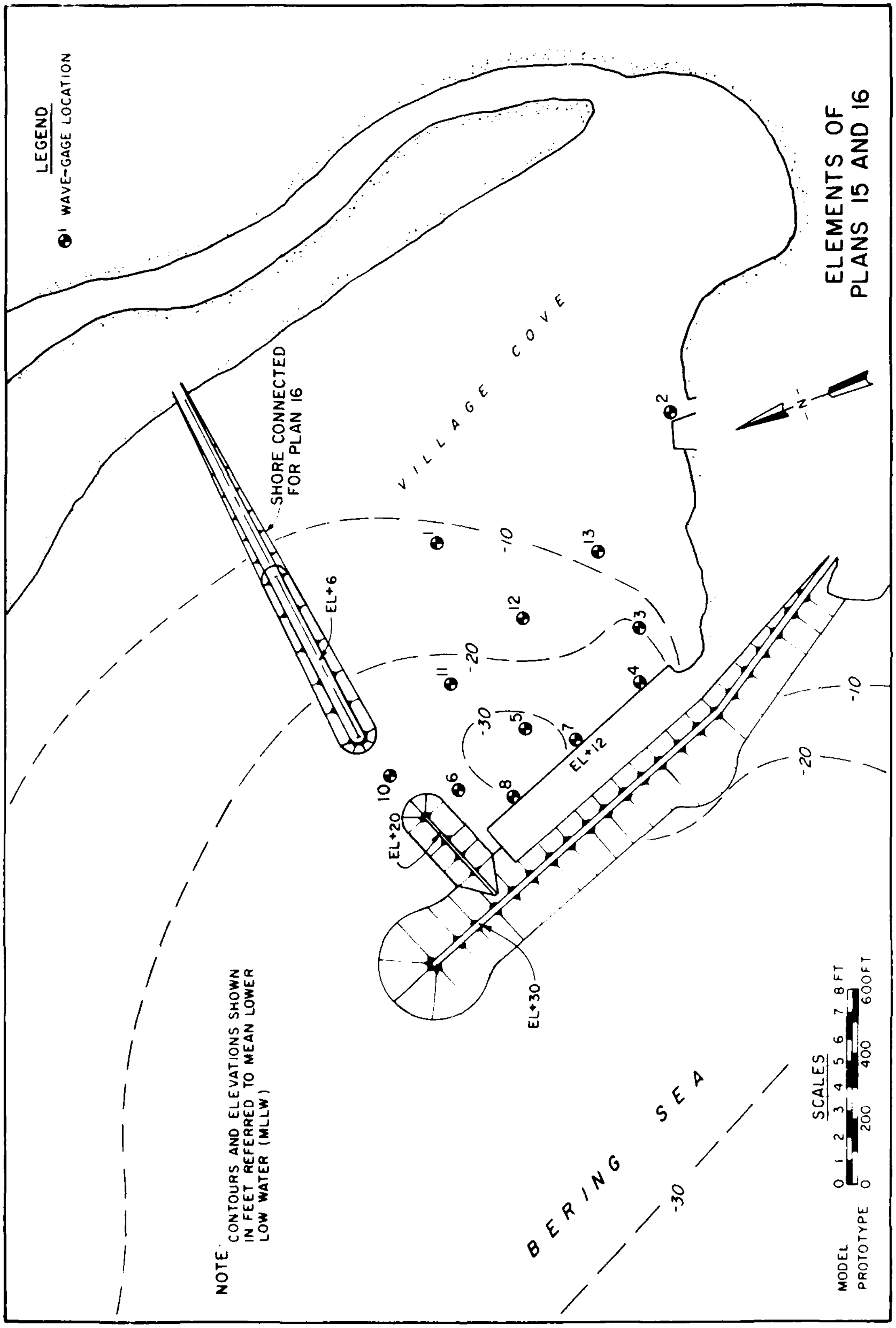

LEGEND
WAVE-GAGE LOCATION
ELEMENTS OF PLAN 13
VILLAGE COVE
BERING SEA
N
EL+6
EL+12
EL+20
EL+30
-10
-20
-30
1
2
3
4
5
6
7
8
10
11
12
13
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT

PLATE 9



ELEMENTS OF PLAN 14
LEGEND
WAVE-GAGE LOCATION
VILLAGE COVE
BERING SEA
EL+6
EL+12
EL+20
EL+30
-10
-20
-30
N
1
2
3
4
5
6
7
8
9
10
11
12
13
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT



LEGEND
1 WAVE-GAGE LOCATION
ELEMENTS OF
PLANS 15 AND 16
VILLAGE COVE
SHORE CONNECTED
FOR PLAN 16
EL+6
EL+12
EL+20
EL+30
N
-10
-20
-30
1
2
3
4
5
6
7
8
10
11
12
13
BERING SEA
NOTE: CONTOURS AND ELEVATIONS SHOWN
IN FEET REFERRED TO MEAN LOWER
LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT

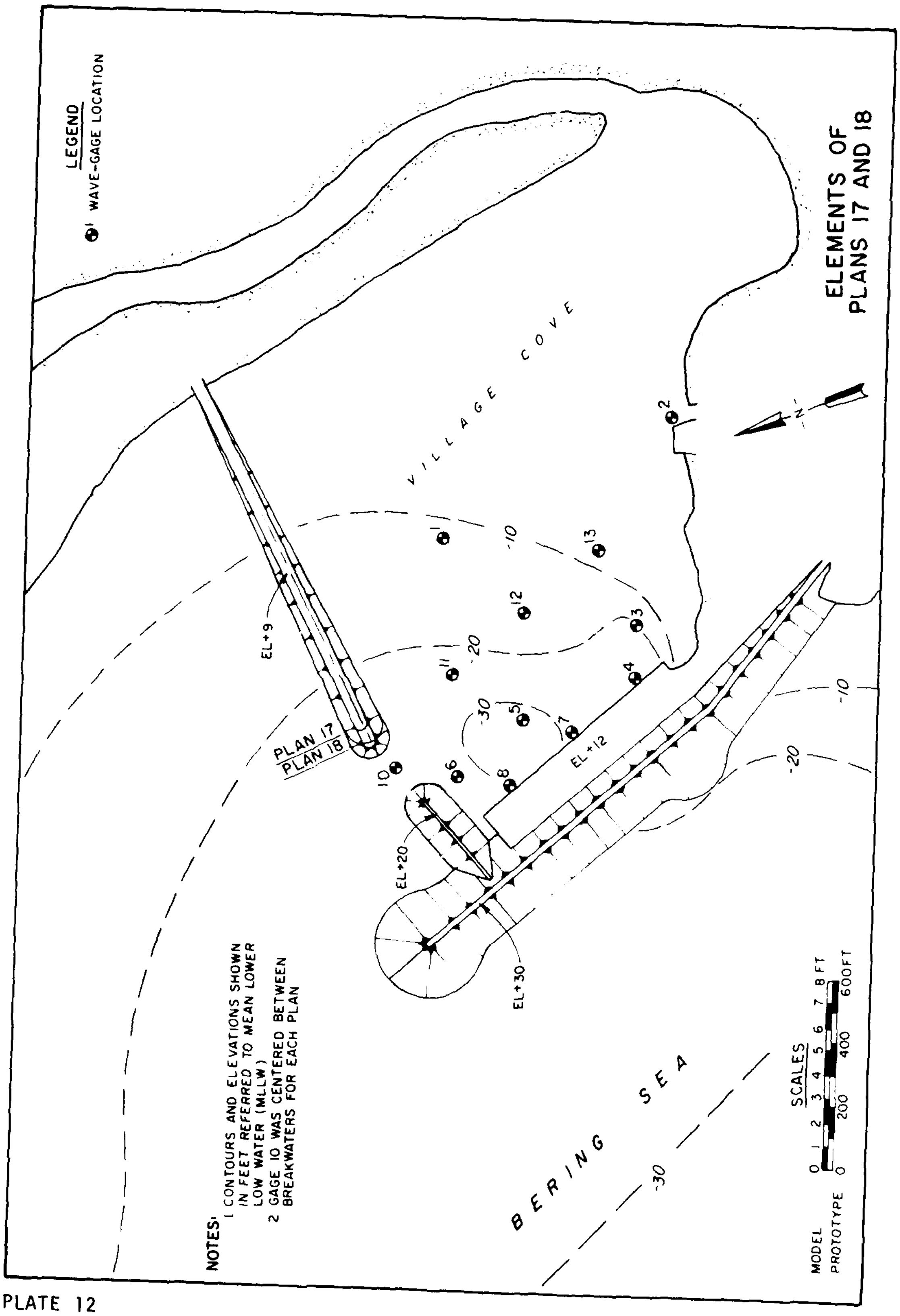
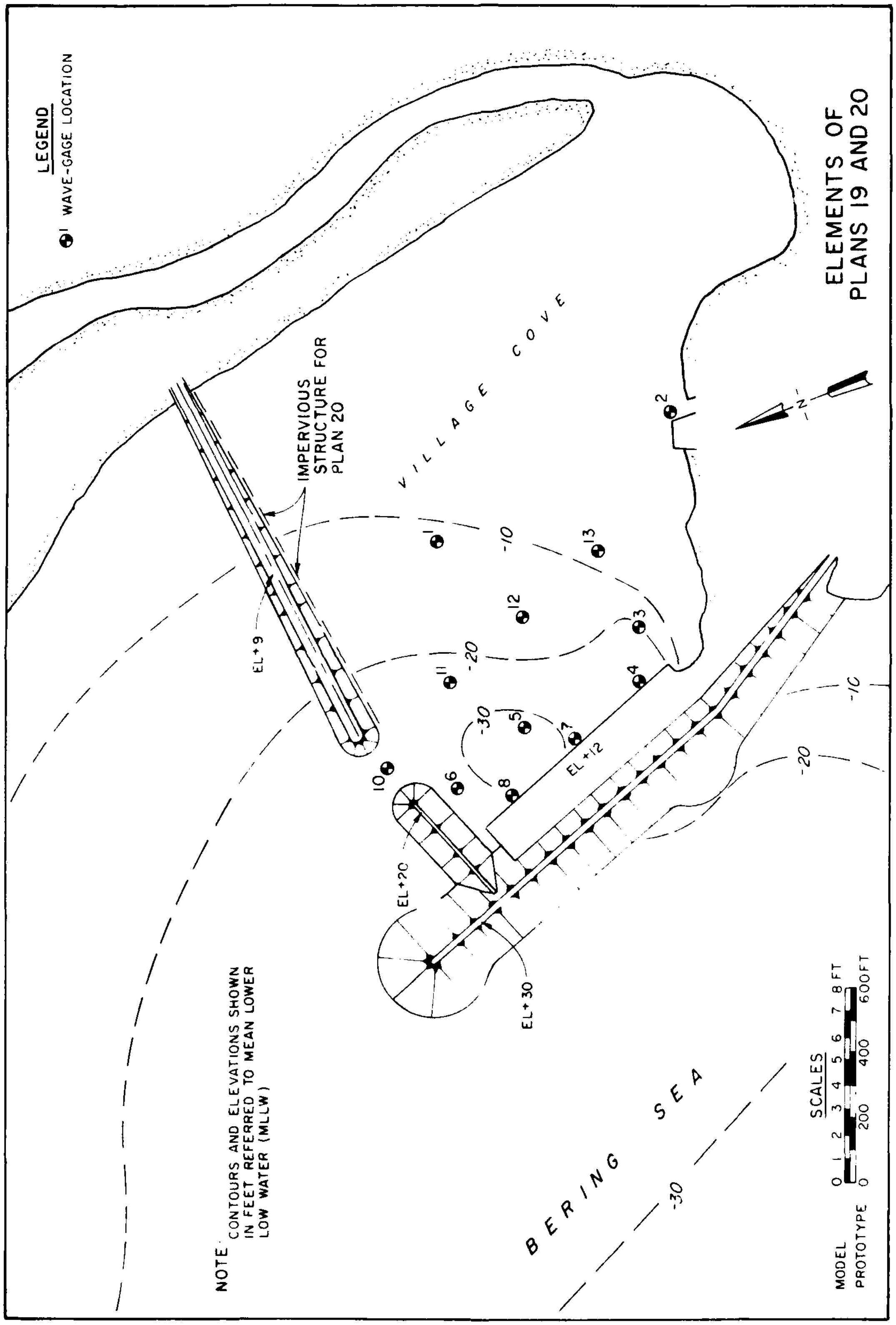
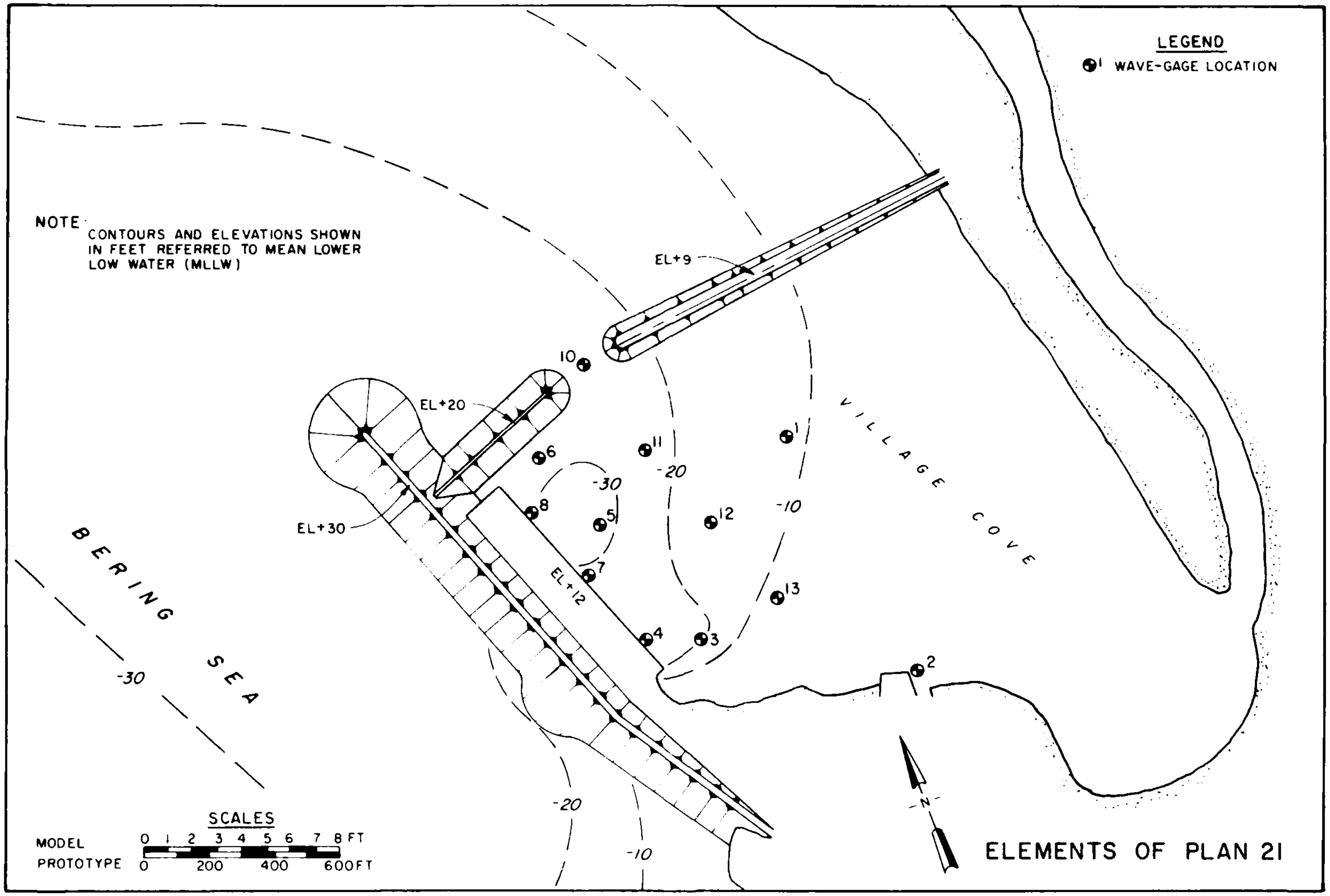
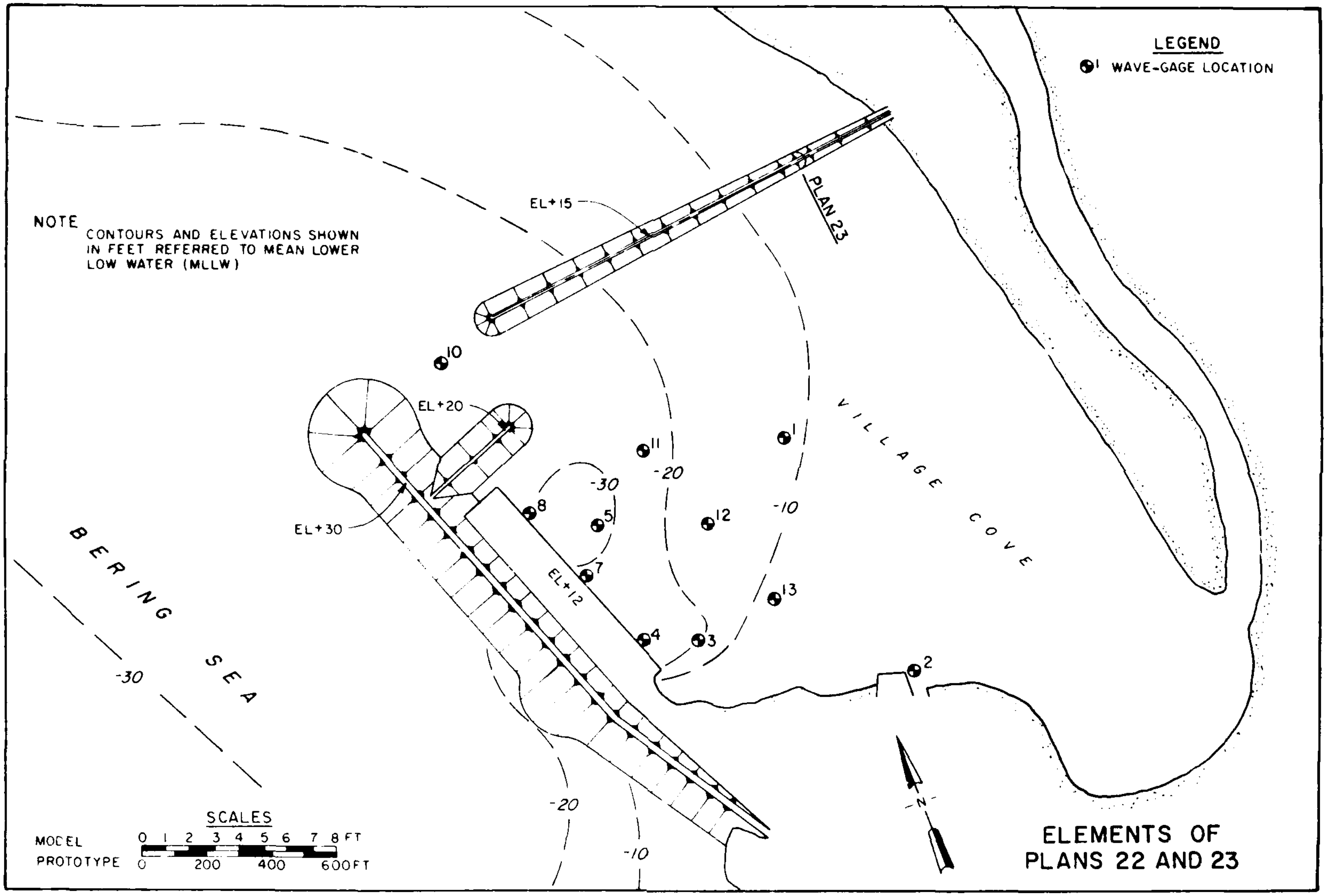

ELEMENTS OF
PLANS 17 AND 18
LEGEND
WAVE-GAGE LOCATION
VILLAGE COVE
BERING SEA
N
EL +9
EL +12
EL +20
EL +30
PLAN 17
PLAN 18
-10
-20
-30
NOTES:
1 CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
2 GAGE 10 WAS CENTERED BETWEEN BREAKWATERS FOR EACH PLAN
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT

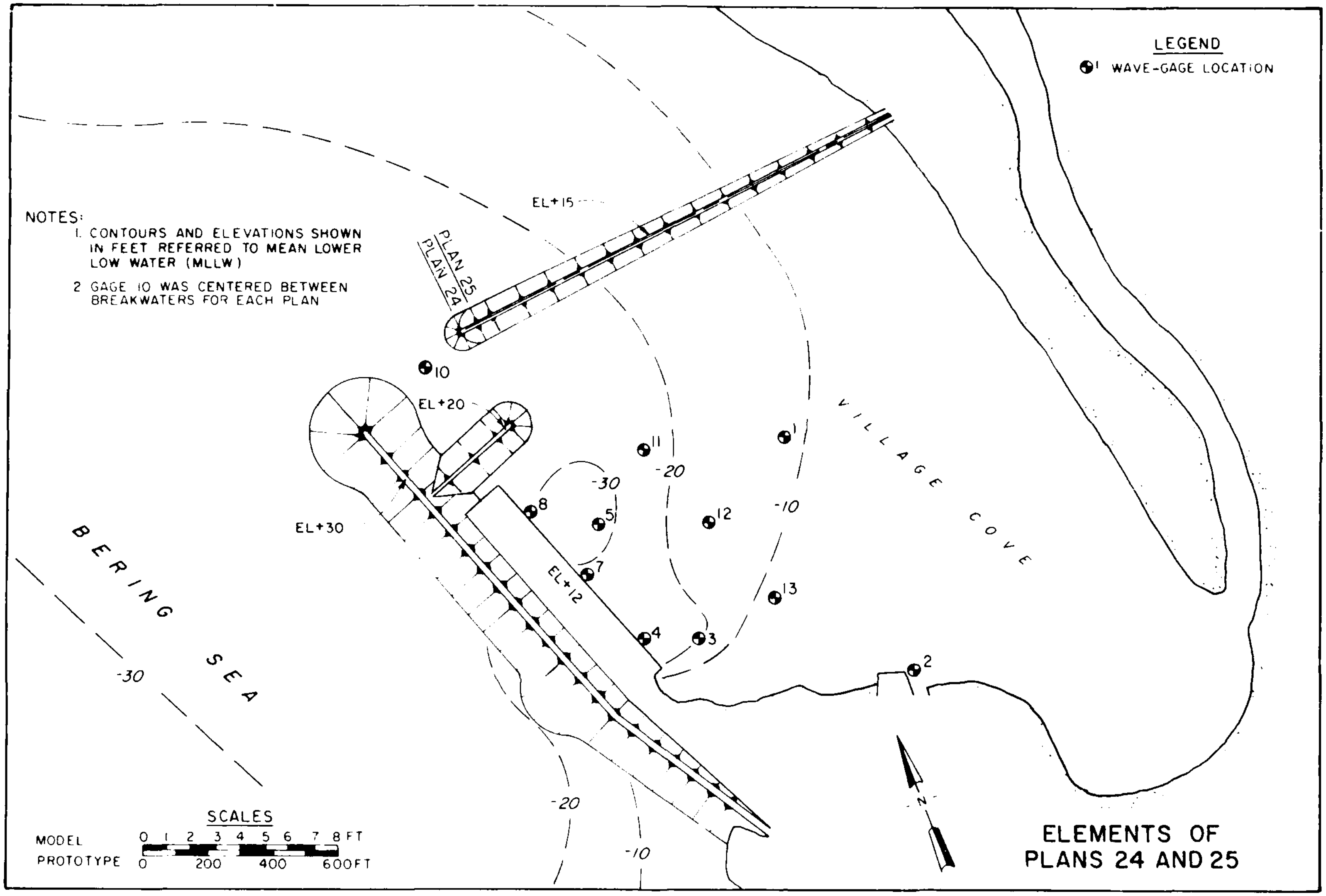
PLATE 12


LEGEND
1 WAVE-GAGE LOCATION
ELEMENTS OF
PLANS 19 AND 20
VILLAGE COVE
IMPERVIOUS
STRUCTURE FOR
PLAN 20
EL + 9
EL + 12
EL + 20
EL + 30
-10
-20
-30
1
2
3
4
5
6
7
8
10
11
12
13
N
BERING SEA
NOTE: CONTOURS AND ELEVATIONS SHOWN
IN FEET REFERRED TO MEAN LOWER
LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT

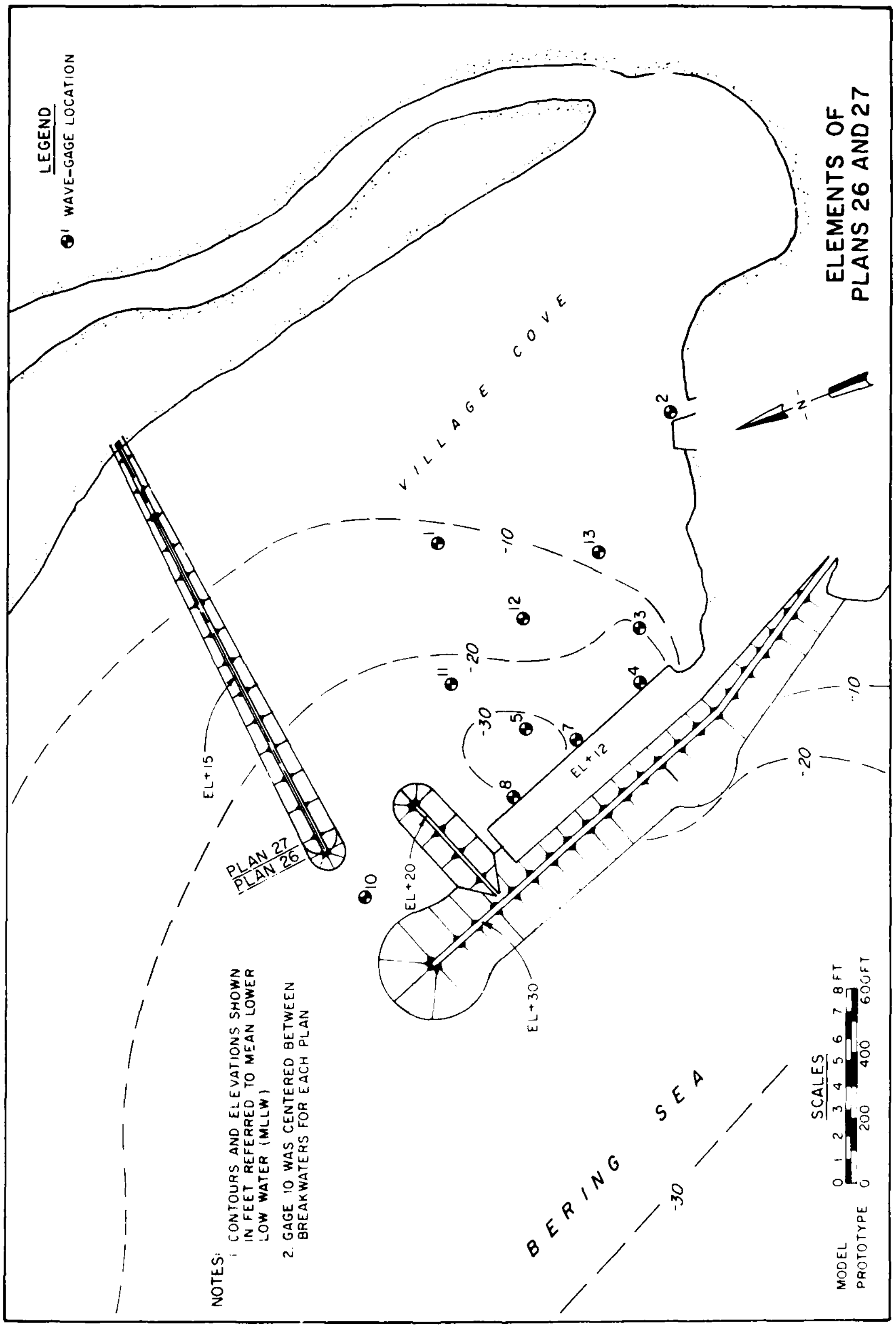


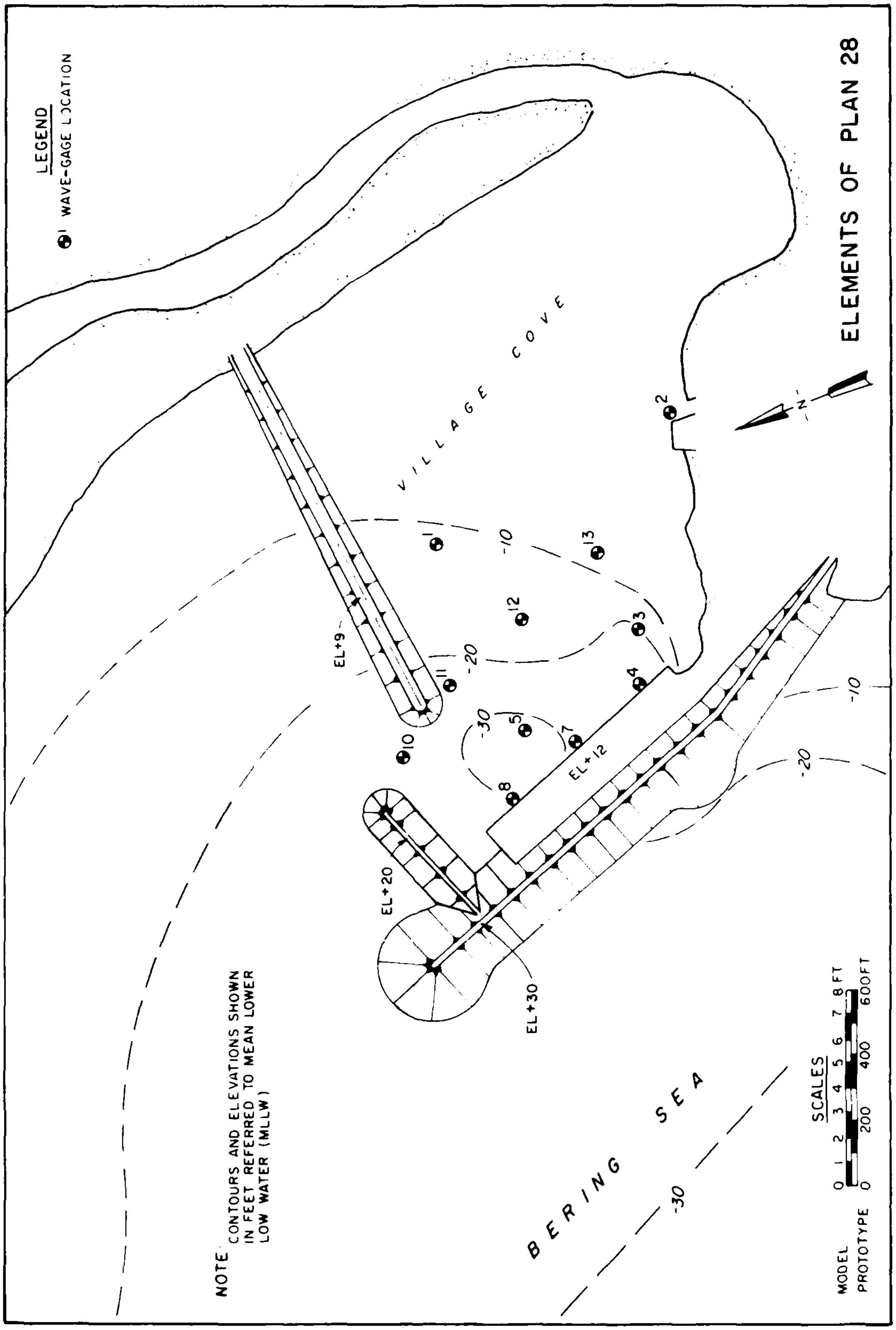
ELEMENTS OF PLAN 21

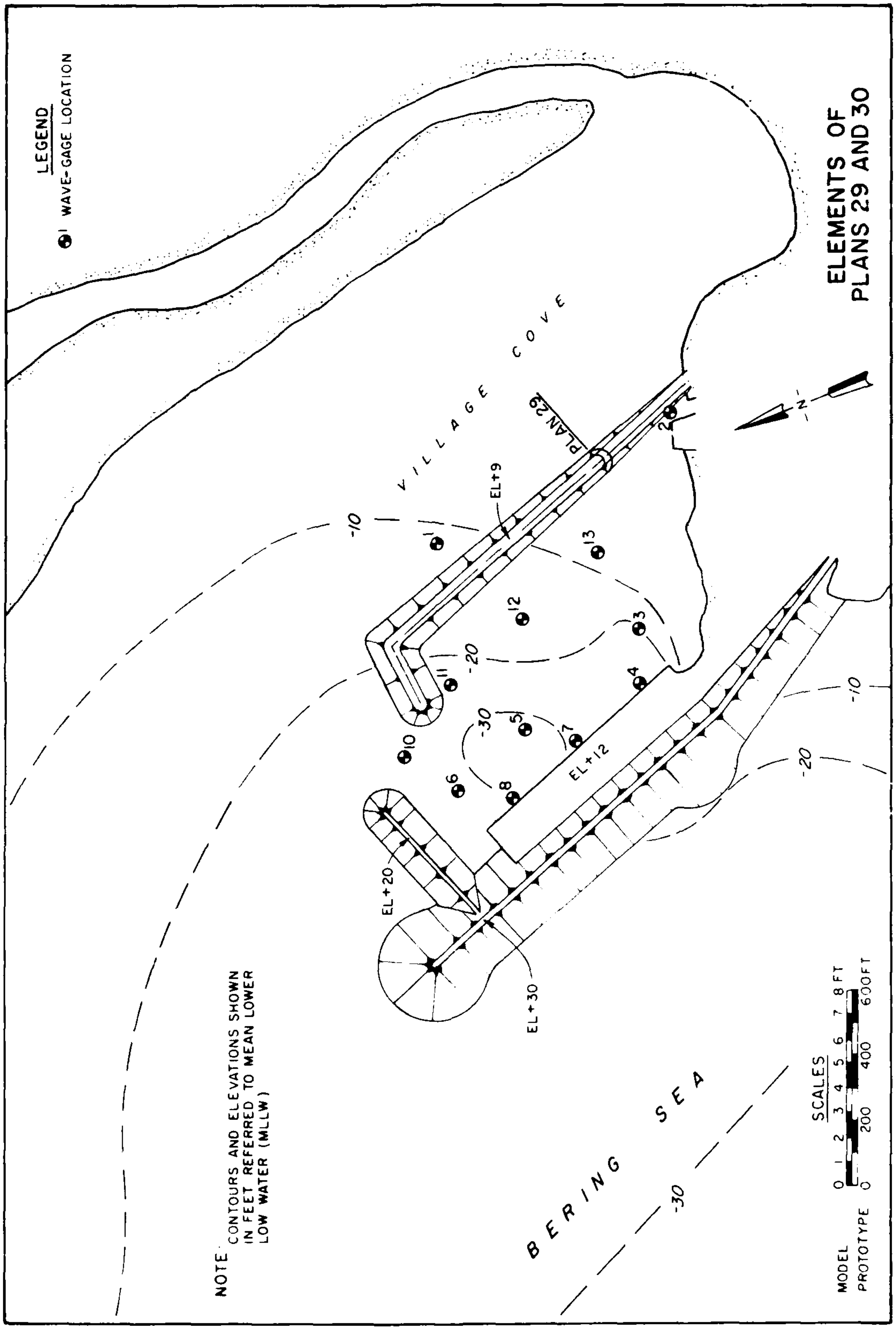

LEGEND
1 WAVE-GAGE LOCATION
NOTE
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
PLAN 23
EL+15
EL+20
EL+30
EL+12
VILLAGE COVE
BERING SEA
-10
-20
-30
N
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT
ELEMENTS OF PLANS 22 AND 23

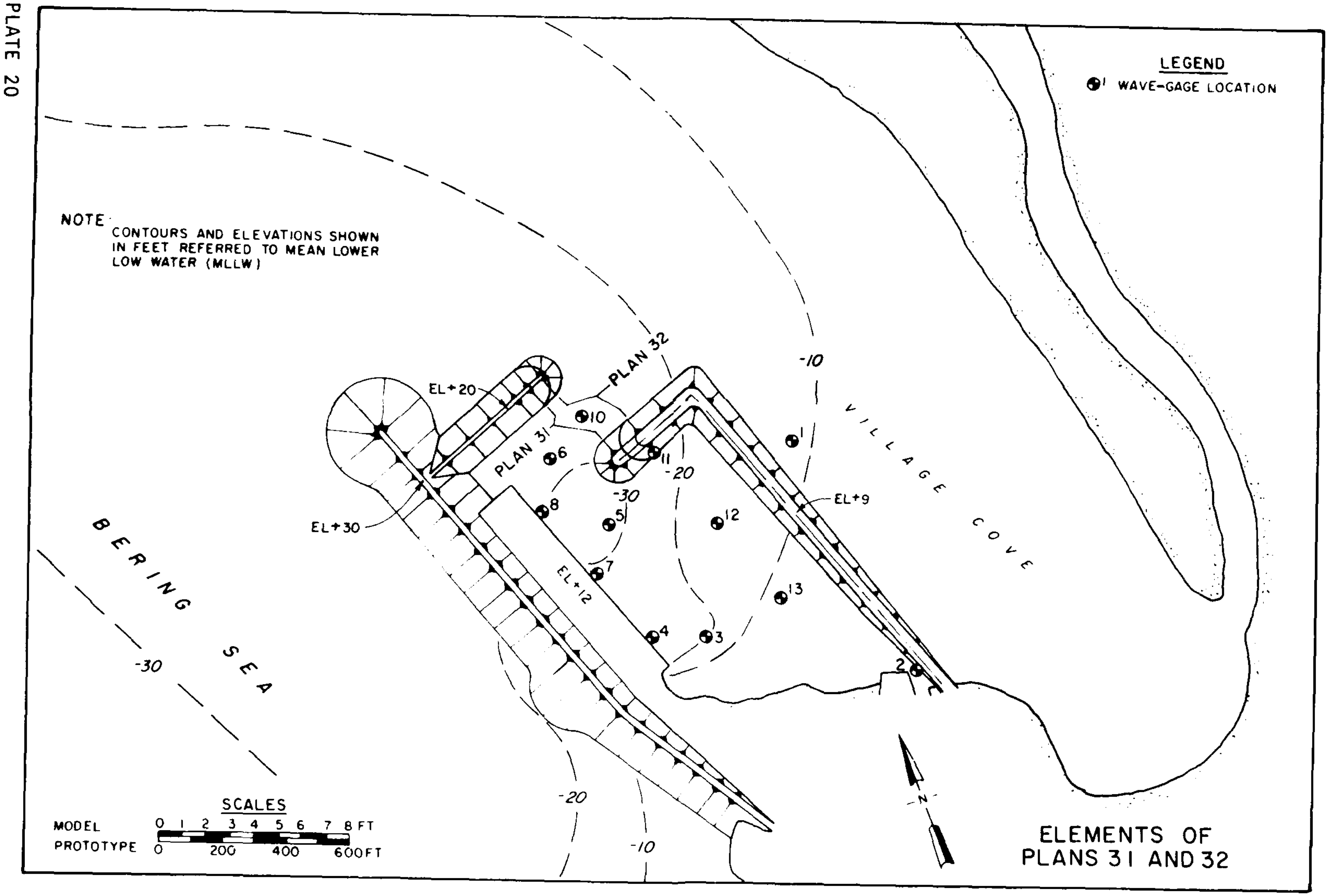


ELEMENTS OF PLANS 24 AND 25

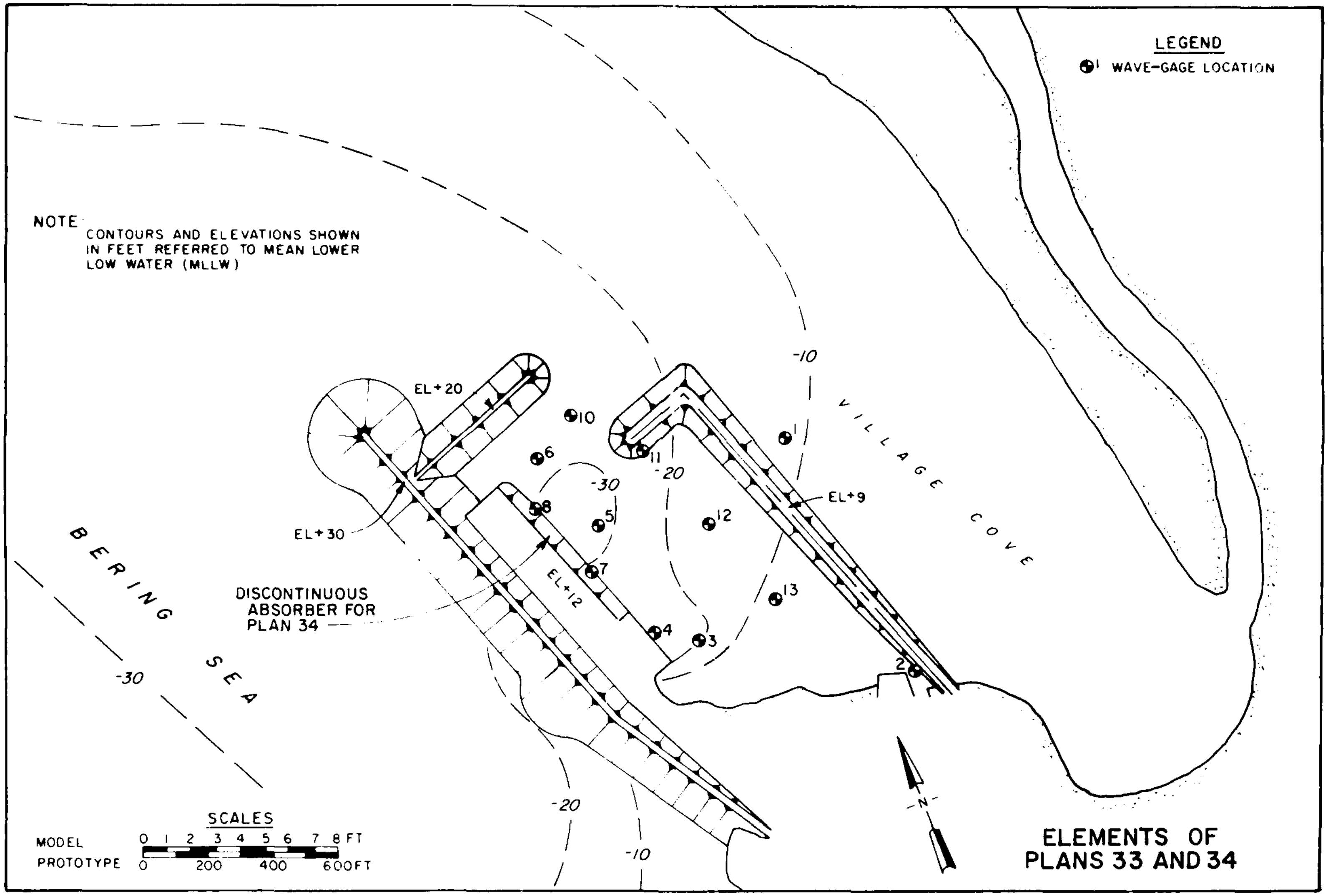

ELEMENTS OF
PLANS 26 AND 27
LEGEND
1 WAVE-GAGE LOCATION
VILLAGE COVE
BERING SEA
PLAN 27
PLAN 26
EL+15
EL+12
EL+20
EL+30
-10
-20
-30
N
1
2
3
4
5
7
8
10
11
12
13
NOTES:
1. CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
2. GAGE 10 WAS CENTERED BETWEEN BREAKWATERS FOR EACH PLAN
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT


ELEMENTS OF PLAN 28
LEGEND
WAVE-GAGE LOCATION
VILLAGE COVE
BERING SEA
EL+9
EL+12
EL+20
EL+30
-10
-20
-30
1
2
3
4
5
7
8
10
11
12
13
N
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT


LEGEND
WAVE-GAGE LOCATION
ELEMENTS OF PLANS 29 AND 30
VILLAGE COVE
PLAN 29
EL+9
EL+12
EL+20
EL+30
BERING SEA
-10
-20
-30
N
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT



ELEMENTS OF PLANS 31 AND 32


LEGEND
1 WAVE-GAGE LOCATION
NOTE
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
VILLAGE COVE
BERING SEA
EL+20
EL+30
EL+12
EL+9
DISCONTINUOUS ABSORBER FOR PLAN 34
-10
-20
-30
1
2
3
4
5
6
7
8
10
11
12
13
N
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT
ELEMENTS OF PLANS 33 AND 34

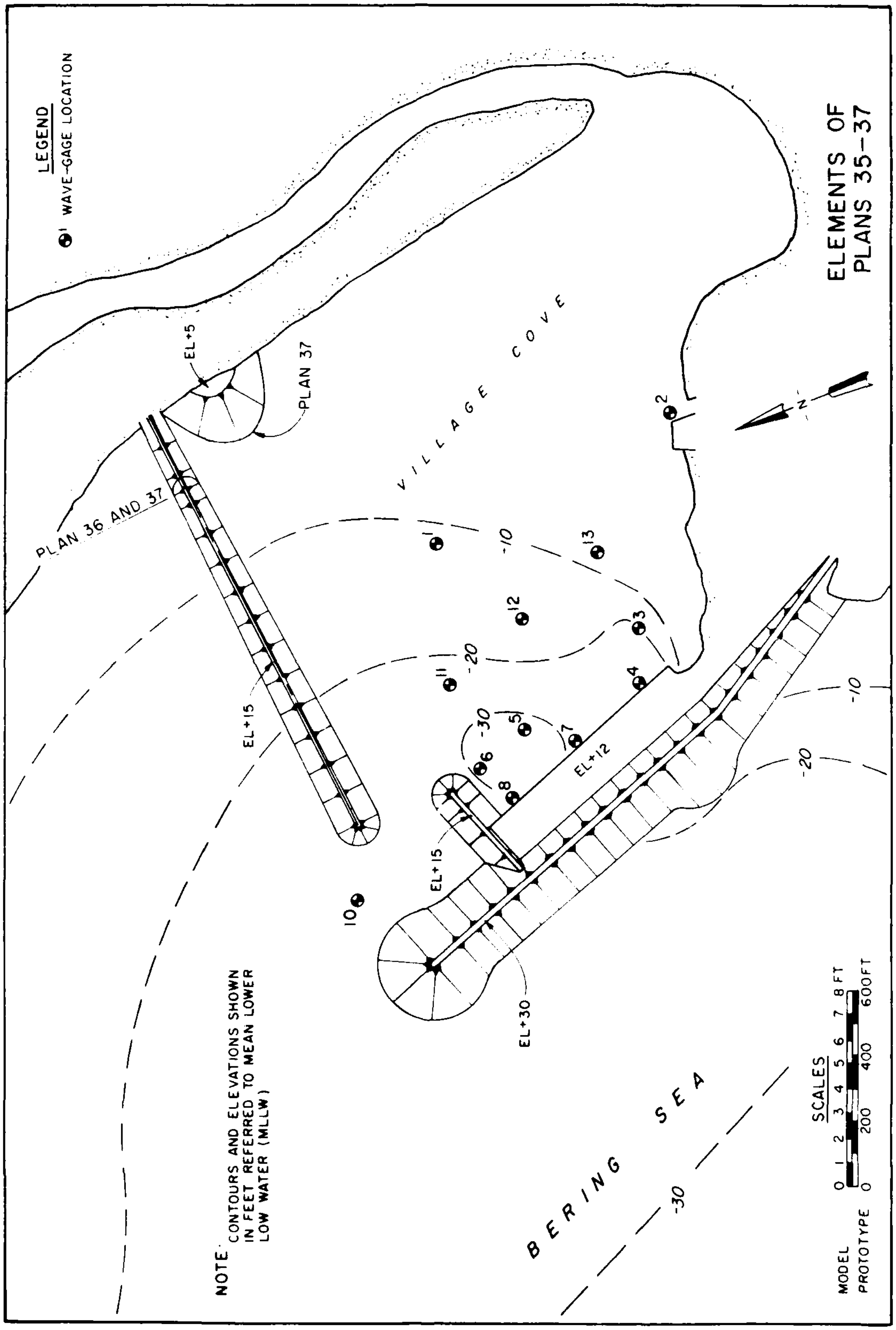
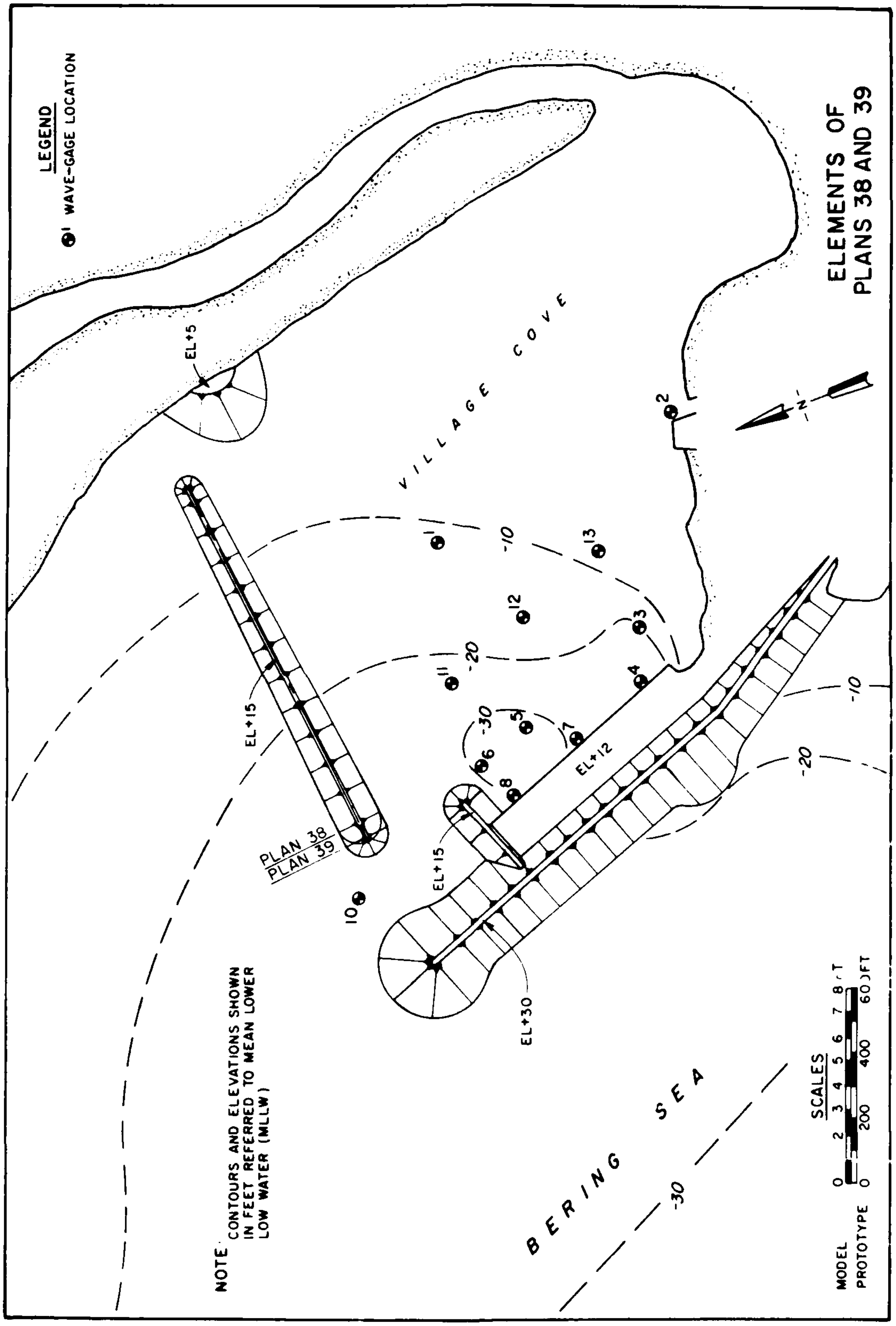
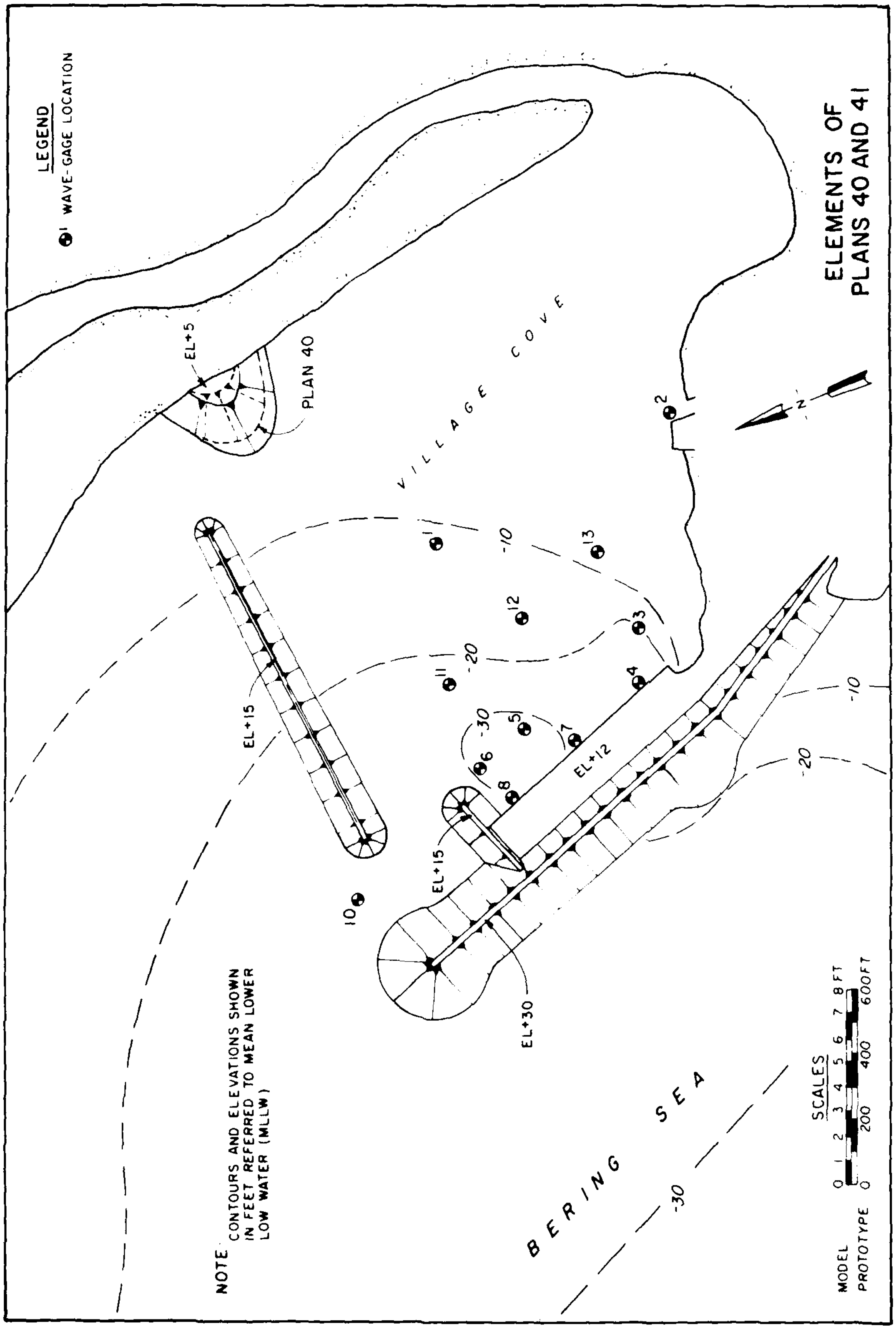
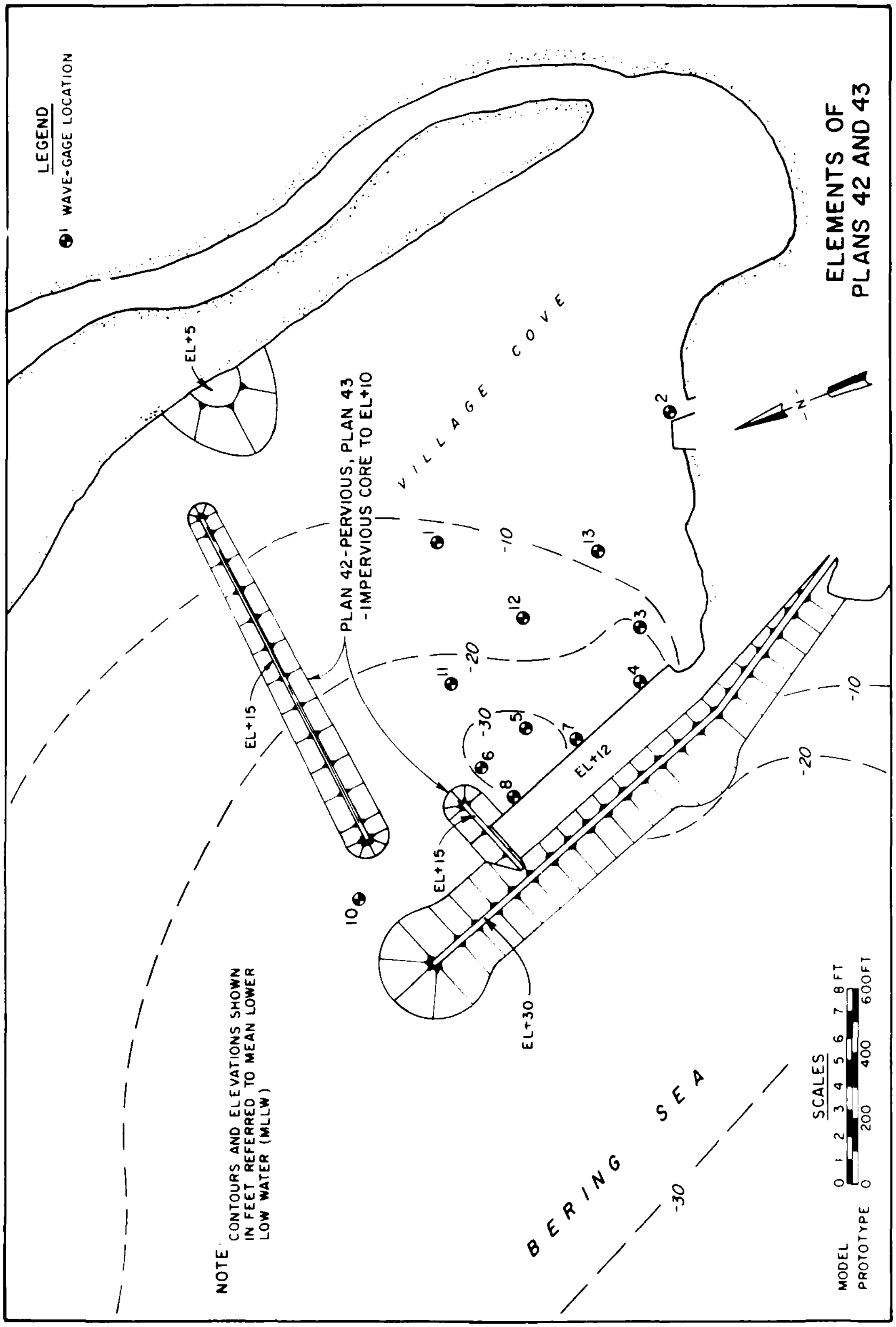

ELEMENTS OF PLANS 35–37
LEGEND
WAVE-GAGE LOCATION
VILLAGE COVE
BERING SEA
PLAN 37
PLAN 36 AND 37
EL+5
EL+15
EL+12
EL+30
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT
N

PLATE 22



ELEMENTS OF PLANS 38 AND 39


LEGEND
WAVE-GAGE LOCATION
ELEMENTS OF
PLANS 40 AND 41
VILLAGE COVE
PLAN 40
EL+5
EL+15
EL+12
EL+15
EL+30
N
-10
-20
-30
-10
-20
-30
1
2
3
4
5
6
7
8
10
11
12
13
BERING SEA
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT


ELEMENTS OF
PLANS 42 AND 43
LEGEND
1 WAVE-GAGE LOCATION
VILLAGE COVE
BERING SEA
PLAN 42-PERVIOUS, PLAN 43
-IMPERVIOUS CORE TO EL+10
EL+5
EL+15
EL+15
EL+12
EL+30
-10
-20
-30
-10
-20
-30
1
2
3
4
5
6
7
8
10
11
12
13
N
NOTE: CONTOURS AND ELEVATIONS SHOWN
IN FEET REFERRED TO MEAN LOWER
LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT

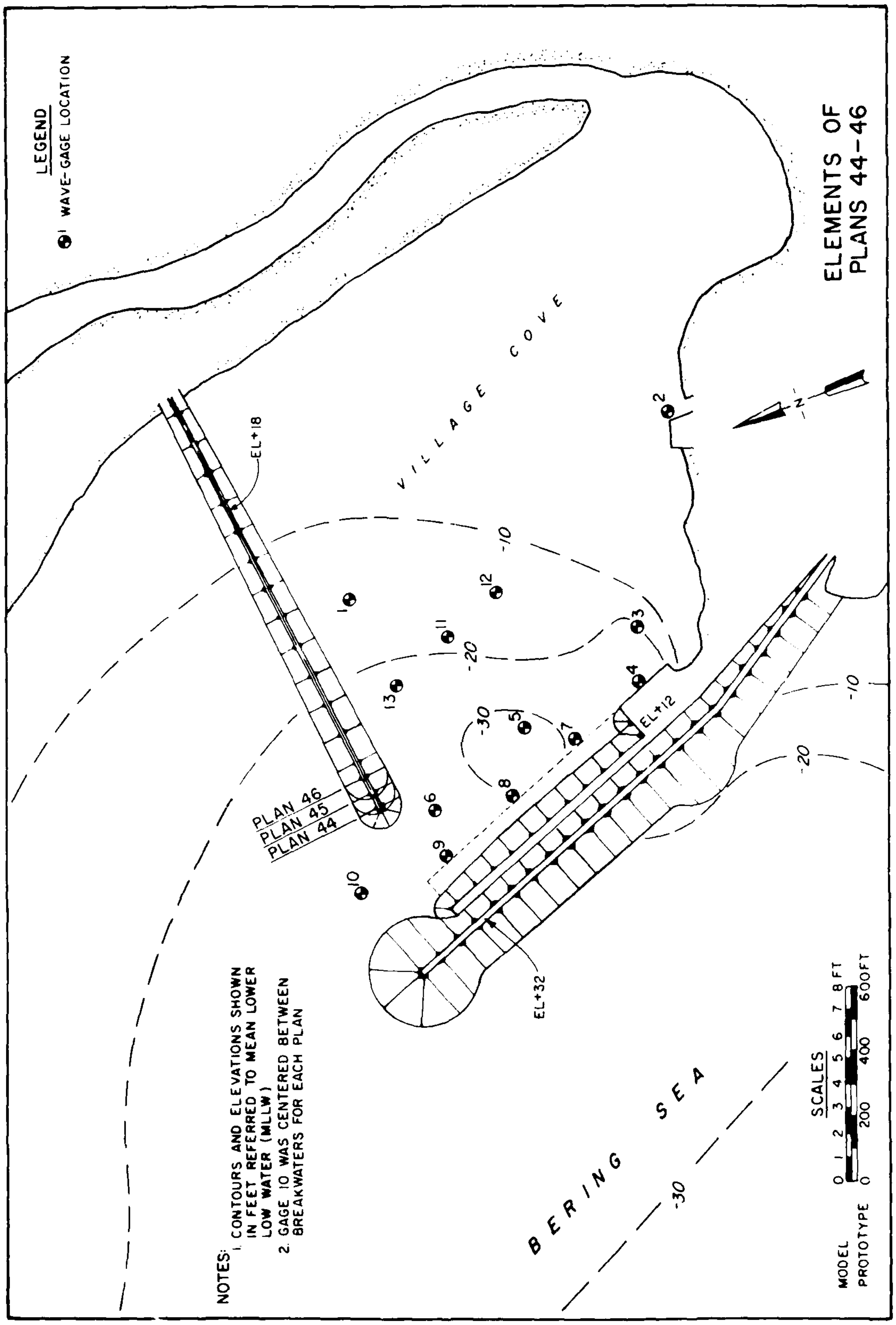
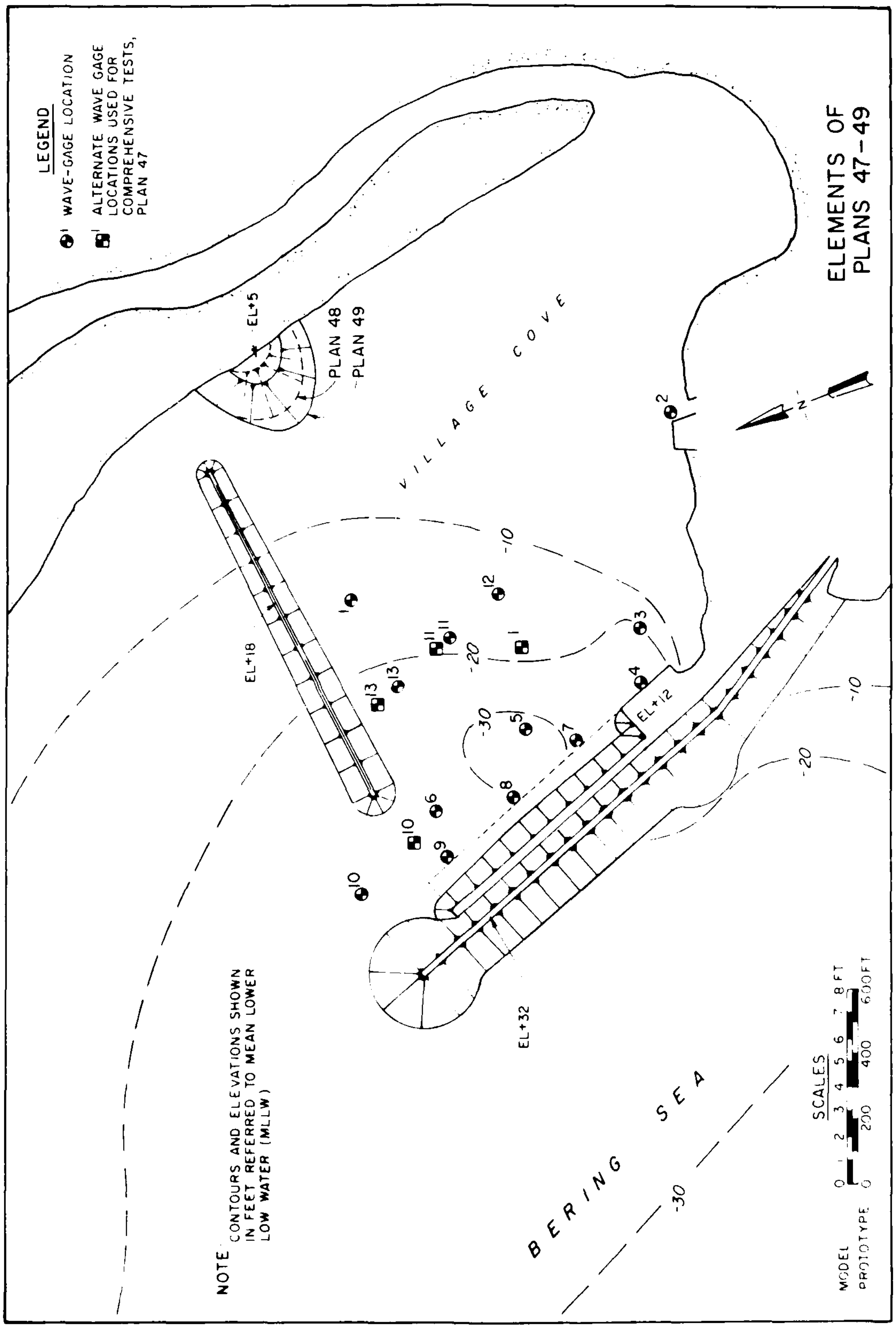
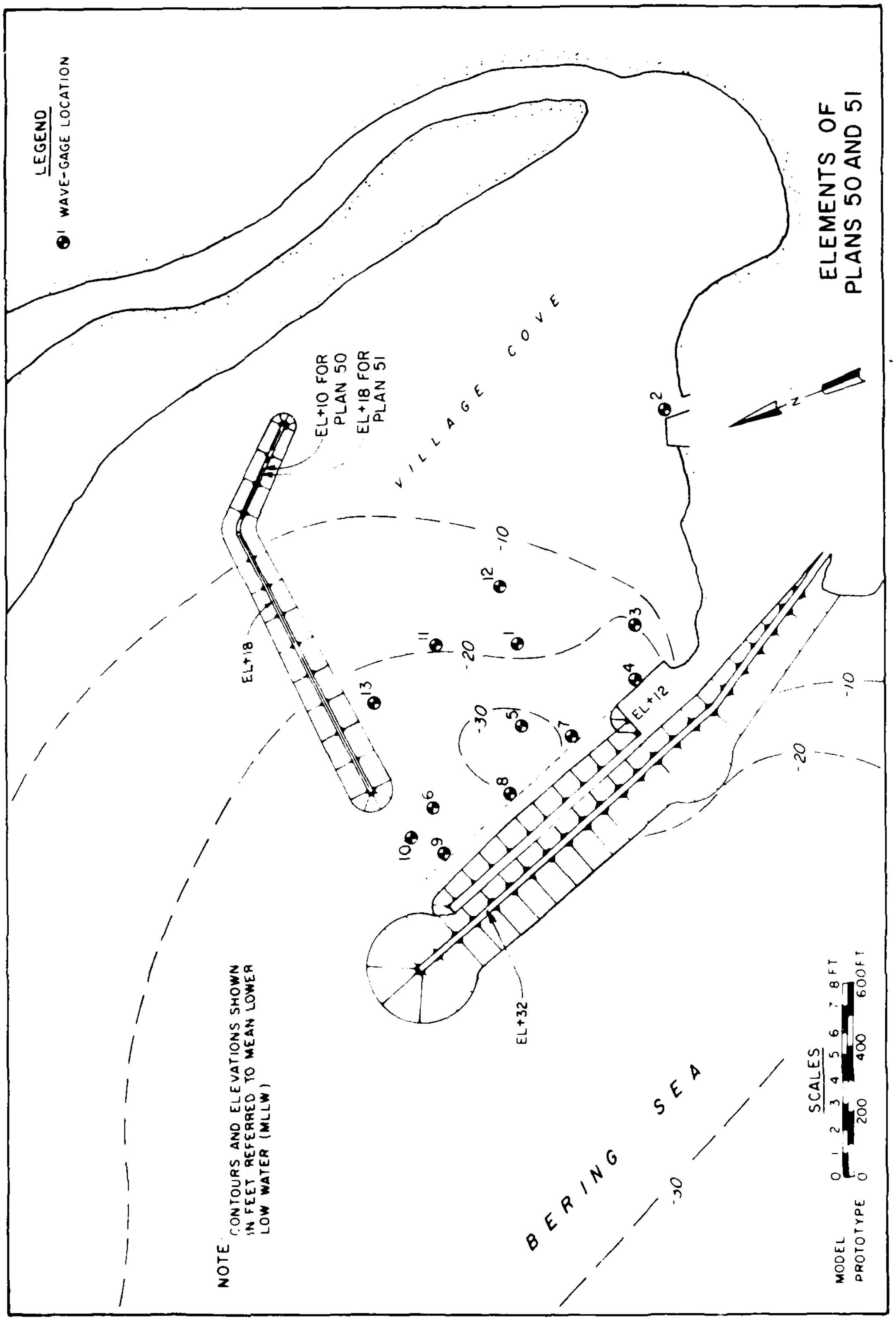
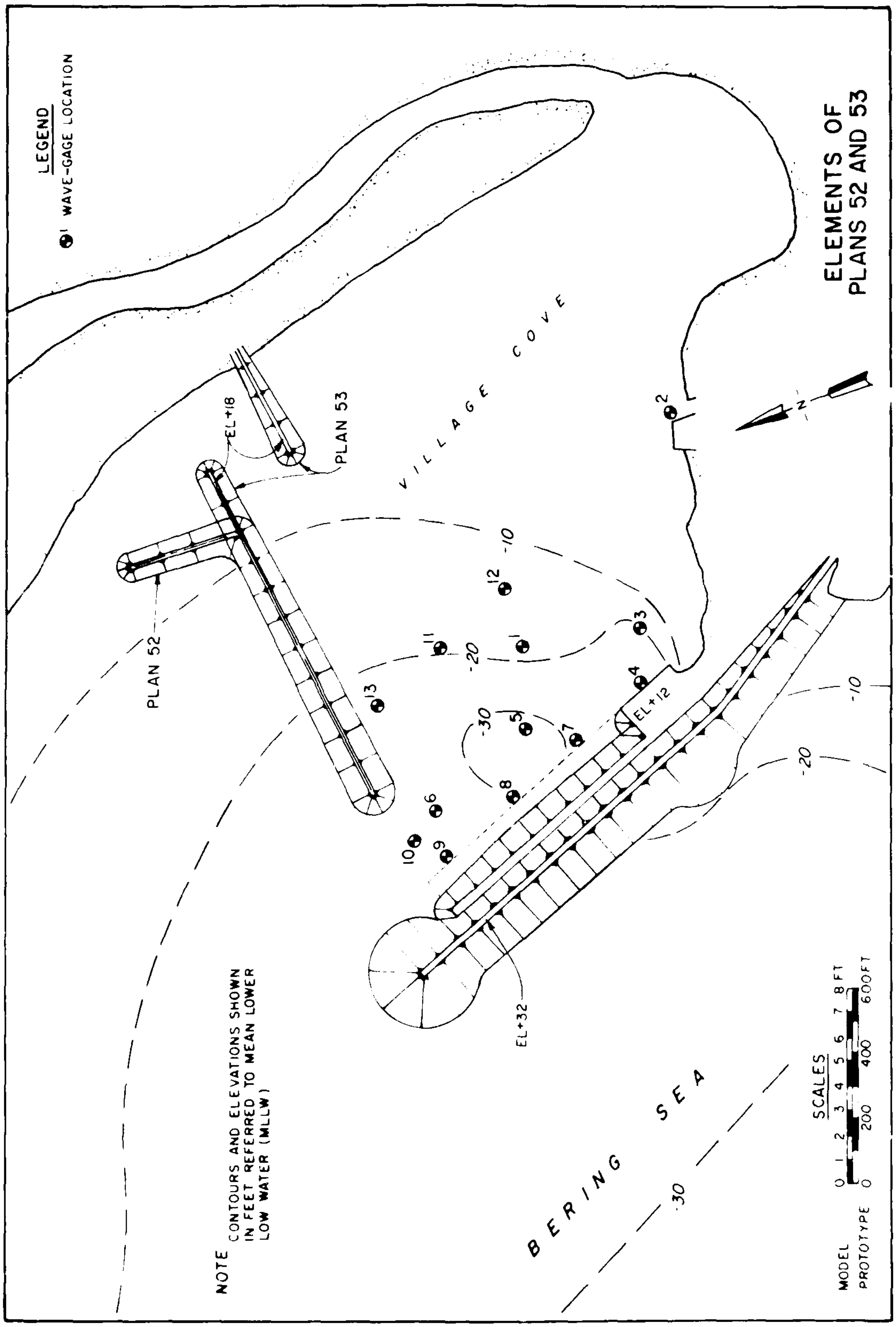

LEGEND
1 WAVE-GAGE LOCATION
ELEMENTS OF
PLANS 44-46
VILLAGE COVE
N
EL+18
EL+12
EL+32
PLAN 46
PLAN 45
PLAN 44
-10
-20
-30
1
2
3
4
5
6
7
8
9
10
11
12
13
NOTES:
1. CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
2. GAGE 10 WAS CENTERED BETWEEN BREAKWATERS FOR EACH PLAN
BERING SEA
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT

PLATE 26


LEGEND
WAVE-GAGE LOCATION
ALTERNATE WAVE GAGE LOCATIONS USED FOR COMPREHENSIVE TESTS, PLAN 47
ELEMENTS OF PLANS 47-49
EL +5
PLAN 48
PLAN 49
VILLAGE COVE
N
EL +18
EL +12
EL +32
BERING SEA
NOTE CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT



ELEMENTS OF PLANS 50 AND 51



ELEMENTS OF PLANS 52 AND 53

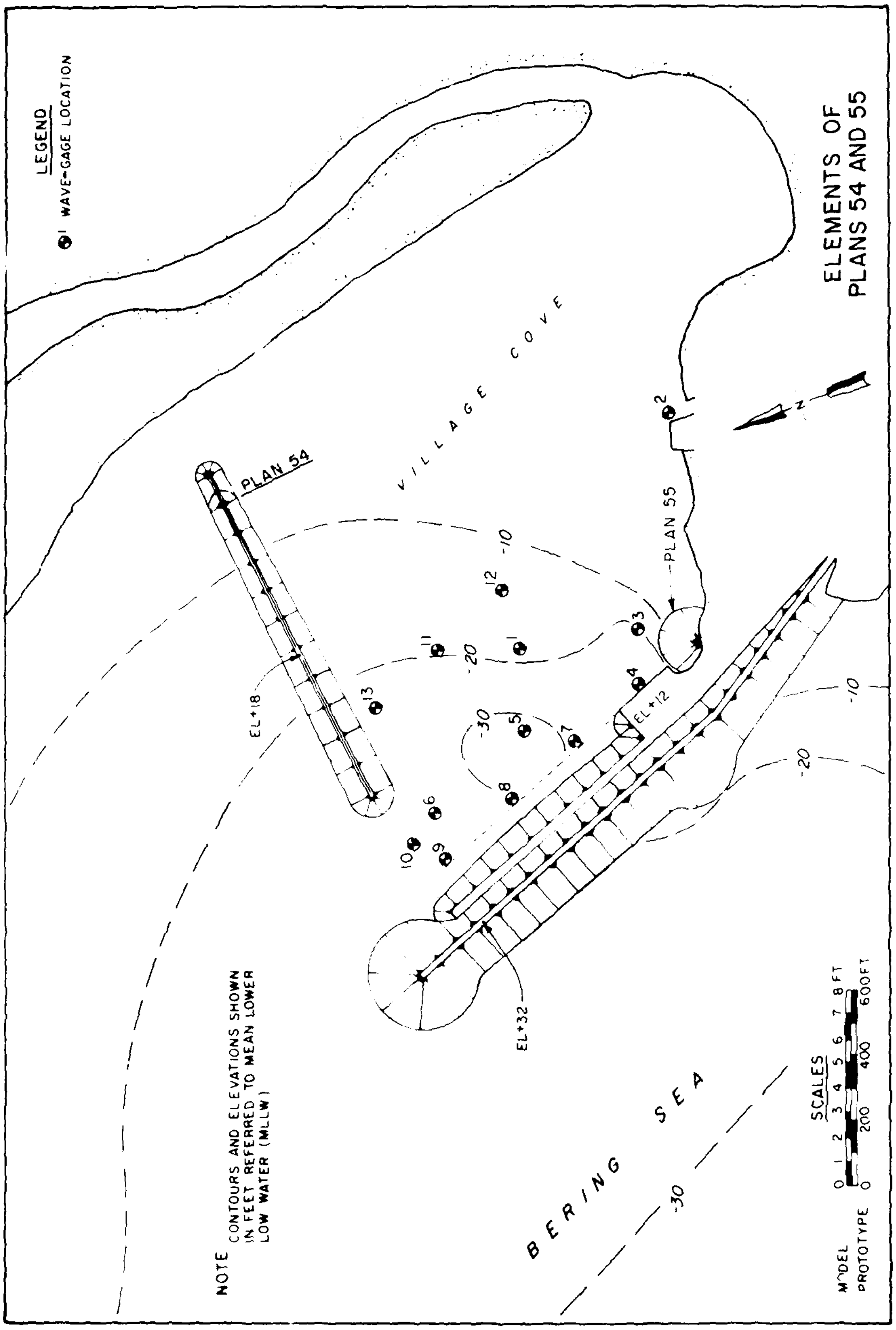
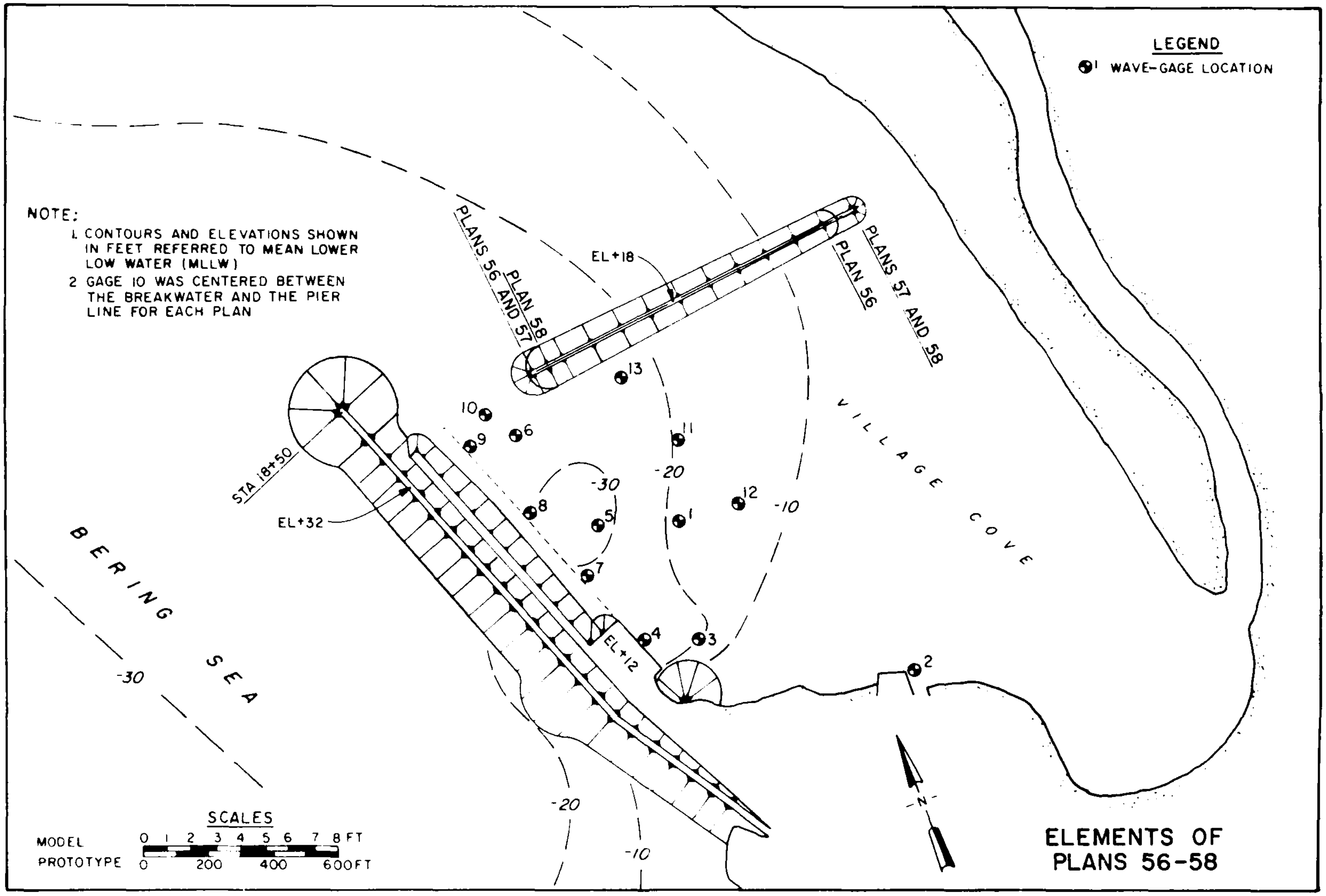
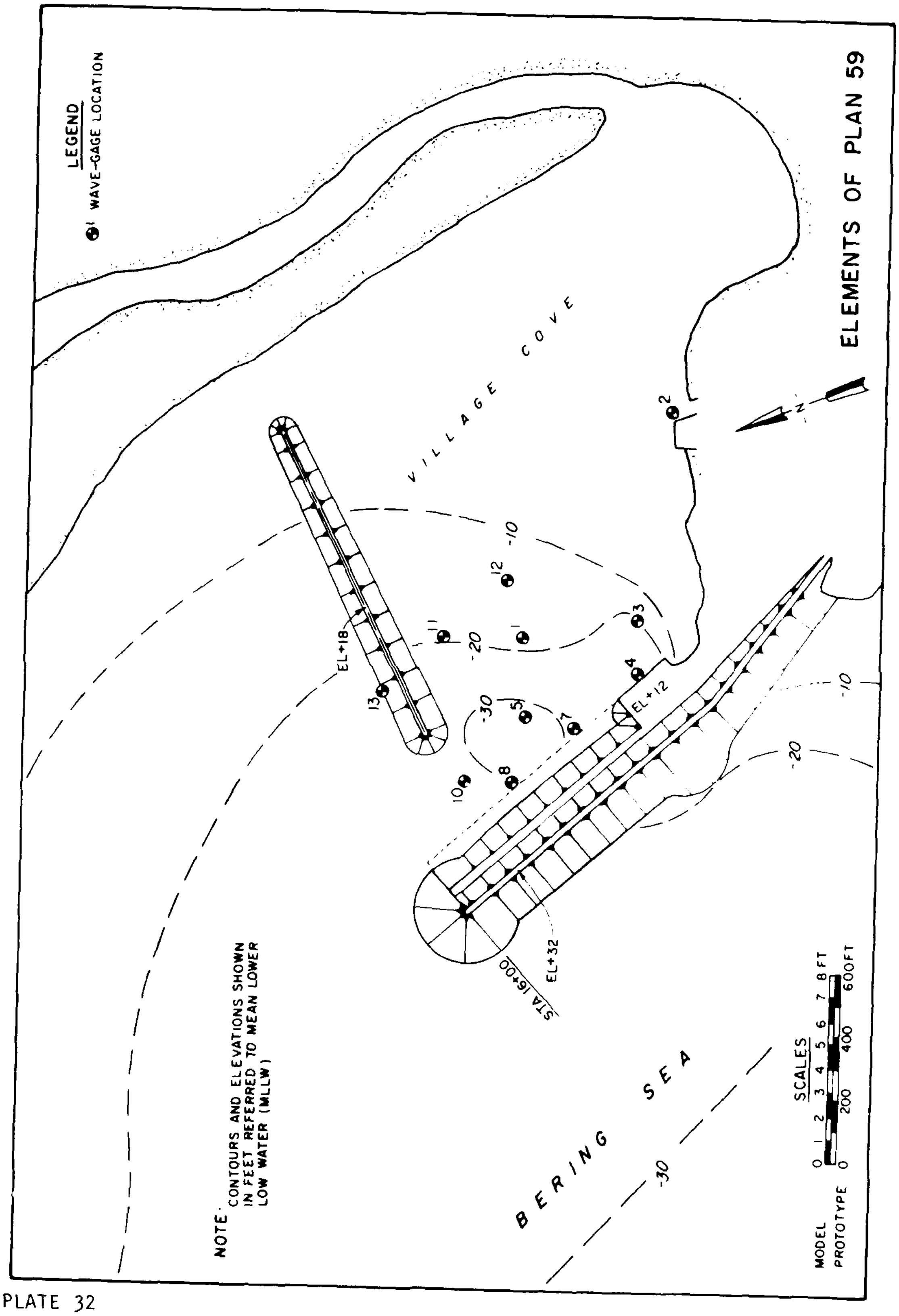

ELEMENTS OF PLANS 54 AND 55
LEGEND
1 WAVE-GAGE LOCATION
VILLAGE COVE
PLAN 54
PLAN 55
EL+18
EL+12
EL+32
-10
-20
-30
BERING SEA
NOTE CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT
N

PLATE 30


LEGEND
1 WAVE-GAGE LOCATION
NOTE:
1. CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
2. GAGE 10 WAS CENTERED BETWEEN THE BREAKWATER AND THE PIER LINE FOR EACH PLAN
PLAN 58
PLANS 56 AND 57
PLANS 57 AND 58
PLAN 56
EL+18
EL+32
EL+12
STA 18+50
VILLAGE COVE
BERING SEA
-10
-20
-30
1
2
3
4
5
6
7
8
9
10
11
12
13
N
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT
ELEMENTS OF PLANS 56-58


ELEMENTS OF PLAN 59
LEGEND
WAVE-GAGE LOCATION
VILLAGE COVE
BERING SEA
EL+18
EL+12
EL+32
STA 16+00
-10
-20
-30
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 0 1 2 3 4 5 6 7 8 FT
PROTOTYPE 0 200 400 600 FT
N